RONALD L. OLSON (SBN 44597)
Ronald.Olson@mto.com
DANIEL P. COLLINS (SBN 139164)
Daniel.Collins@mto.com
MUNGER, TOLLES & OLSON LLP
355 South Grand Avenue, 35th Floor
Los Angeles, CA 90071-1560
Telephone: (213) 683-9100
Facsimile: (213) 687-3702

JEROME C. ROTH (SBN 159483)
Jerome.Roth@mto.com
MUNGER, TOLLES & OLSON LLP
560 Mission Street
San Francisco, CA 94105-2907
Telephone: (415) 512-4000
Facsimile: (415) 512-4077

Attorneys for Defendant
SHELL OIL COMPANY

[*Counsel Listing Continued on Next Page*]

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

OAKLAND DIVISION

NATIVE VILLAGE OF KIVALINA and CITY OF KIVALINA, Plaintiffs, vs. EXXON MOBIL CORPORATION; BP P.L.C.; BP AMERICA, INC.; BP PRODUCTS NORTH AMERICA, INC.; CHEVRON CORPORATION; CHEVRON U.S.A., INC.; CONOCOPHILLIPS COMPANY; ROYAL DUTCH SHELL PLC; SHELL OIL COMPANY; PEABODY ENERGY CORPORATION; THE AES CORPORATION; AMERICAN ELECTRIC POWER COMPANY, INC.; AMERICAN ELECTRIC POWER SERVICES CORPORATION; DTE ENERGY COMPANY; DUKE ENERGY CORPORATION; DYNEGY HOLDINGS, INC.; EDISON INTERNATIONAL; MIDAMERICAN ENERGY HOLDINGS COMPANY; MIRANT CORPORATION; NRG ENERGY; PINNACLE WET CAPITAL CORPORATION; RELIANT ENERGY, INC.; THE SOUTHERN COMPANY; AND XCEL ENERGY, INC., Defendants.	CASE NO. C 08-01138 SBA **DECLARATION OF DANIEL P. COLLINS IN SUPPORT OF MOTION OF CERTAIN OIL COMPANY DEFENDANTS TO DISMISS PLAINTIFFS' COMPLAINT PURSUANT TO FED. R. CIV. P. 12(b)(1)** Time: December 9, 2008, 1:00 P.M. Ctrm.: Courtroom 3, 1301 Clay Street, Oakland, California The Honorable Saundra B. Armstrong

JOHN F. DAUM (SBN 52313)
jdaum@omm.com
O'MELVENY & MYERS LLP
400 South Hope Street
Los Angeles, CA 90071-2899
Telephone: (213) 430-6111
Facsimile: (213) 430-6407

JONATHAN D. HACKER (*Pro hac vice pending*)
jhacker@omm.com
O'MELVENY & MYERS LLP
1625 Eye Street, NW
Washington, DC 20006-4001
Telephone: (202) 383-5300
Facsimile: (202) 383-5414

Attorneys for Defendant
EXXON MOBIL CORPORATION

ROBERT MEADOWS (*Pro hac vice*)
rmeadows@kslaw.com
TRACIE J. RENFROE (*Pro hac vice*)
trenfroe@kslaw.com
JONATHAN L. MARSH (*Pro hac vice*)
jlmarsh@kslaw.com
KING & SPALDING LLP
1100 Louisiana Street, Suite 4000
Houston, TX 77002-5213
Telephone: (713) 751-3200
Facsimile: (713) 751-3290

LISA KOBIALKA (SBN 191404)
lkobialka@kslaw.com
KING & SPALDING LLP
1000 Bridge Parkway, Suite 100
Redwood City, CA 94065
Telephone: (650) 590-0700
Facsimile: (650) 590-1900

Attorneys for Defendants
CHEVRON CORPORATION and
CHEVRON U.S.A. INC.

STUART A. C. DRAKE (*Pro hac vice*)
sdrake@kirkland.com
ANDREW B. CLUBOK (*Pro hac vice*)
aclubok@kirkland.com
SUSAN E. ENGEL (*Pro hac vice*)
KIRKLAND & ELLIS LLP
655 Fifteenth Street, N.W.
Washington, D.C. 20005
Telephone: (202) 879-5173
Facsimile: (202) 879-5200

ELIZABETH DEELEY (SBN 230798)
edeeley@kirkland.com
KIRKLAND & ELLIS LLP
555 California Street
San Francisco, CA 94104
Telephone: (415) 439-1861
Facsimile: (415) 439-1500

Attorneys for CONOCOPHILLIPS COMPANY

MATTHEW HEARTNEY (SBN 123516)
Matthew.Heartney@aporter.com
ARNOLD & PORTER LLP
777 S. Figueroa Street, 44th Floor
Los Angeles, CA 90017-5844
Telephone: (213) 243-4150
Facsimile: (213) 243-4199

PHILIP H. CURTIS (*Pro hac vice*)
Philip.Curtis@aporter.com
MICHAEL B. GERRARD (*Pro hac vice*)
Michael.Gerrard@ aporter.com
ARNOLD & PORTER LLP
399 Park Avenue
New York, New York 10022
Telephone: (212) 715-1000
Facsimile: (212) 715-1399

Attorneys for BP AMERICA INC., AND
BP PRODUCTS NORTH AMERICA INC.

DECLARATION OF DANIEL P. COLLINS

I, Daniel P. Collins, do hereby declare as follows:

1. I am a member of the law firm of Munger, Tolles & Olson LLP, counsel of record for Defendant Shell Oil Company in *Native Village of Kivalina, et al. v. Exxon Mobil Corporation*, No. C-08-1138-SBA, which is pending in this Court. I am a member in good standing of the bar of this Court. The matters set forth herein are based upon my own personal knowledge and, if called upon to do so, I could and would testify competently thereto.

2. I and my firm are also among the counsel of record for Shell Oil Company in the appeal in the U.S. Court of Appeals for the Fifth Circuit in *Comer, et al. Murphy Oil USA, et al.*, No. 07-60756. Attached hereto as Exhibit A is a true and correct copy (minus the exhibits thereto) of the Third Amended Complaint that was filed in the *Comer* case in the U.S. District Court for the Southern District of Mississippi, No. 1:05-cv-00436-LG-RHW, which is the district court case that gave rise to the Fifth Circuit appeal noted above. (Neither I nor my firm were counsel of record in the district court proceedings.) I obtained this copy by downloading it from the Southern District of Mississippi's PACER website.

3. Attached hereto as Exhibit B is a true and correct copy of the "Transcript of Hearing on Defendants' Motions to Dismiss" in the *Comer* district court proceedings referenced in paragraph 2. I obtained this copy from my firm's files in the *Comer* matter. (The PACER docket notes the filing of the transcript but does not make the document available electronically.) The attached copy matches the copy of the transcript that was included by the *Comer* plaintiffs in their "Record Excerpts" in the *Comer* appeal in the Fifth Circuit.

4. Attached hereto as Exhibit C is a true and correct copy of the "Order Granting Defendants' Motion to Dismiss" that was filed by the U.S. District Court for the Southern District of Mississippi in the *Comer* case described in paragraph 2. I obtained this copy by downloading it from the Southern District of Mississippi's PACER website.

5. Attached hereto as Exhibit D is a true and correct copy of a document issued by the U.S. Army Corps of Engineers, Alaska District, entitled "*Alaska Village Erosion Technical Assistance Program: An Examination of Erosion Issues in the Communities of Bethel,*

Dillingham, Kaktovik, Kivalina, Newtok, Shishmaref, and Unalakleet," and which bears a date "April 2006." This document is quoted in paragraph 185 of the Plaintiffs' Compliant in *Native Village of Kivalina*, and is cited in footnote 60 of that Complaint. I obtained the attached copy of this document from the U.S. Army Corps of Engineers' website, at the address <http://iss.poa. usace.army.mil/akerosion/references/AVETA%20Report%20-%20Compressed.pdf>.

6. Attached hereto as Exhibit E is a true and correct copy of a document issued by the U.S. General Accounting Office (now known as the "Government Accountability Office"), entitled "*Alaska Native Villages: Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance*" and which bears a date "December 2003." This document is quoted in paragraph 185 of the Plaintiffs' Compliant in *Native Village of Kivalina*, and is cited in footnote 61 of that Complaint. I obtained the attached copy of this document from the U.S. Government Accountability Office's website, at the address < http://www.gao.gov/new.items/d04142.pdf>.

7. Attached hereto as Exhibit F is a true and correct copy of a document issued by the Energy Information Administration, entitled "*Emissions of Greenhouse Gases in the U.S. 2006*." Footnote 45 of the Plaintiffs' Compliant in *Native Village of Kivalina* (the footnote call for footnote 45 is in paragraph 167 of the Complaint), cites a document called "Emissions of Greenhouse Gases in the U.S. 2005," and that footnote gives the following web address for the document: <http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html>. I entered that web address on my internet browser, and the result was a webpage entitled "Emissions of Greenhouse Gases Report." The page contained a link for a PDF version of the report (the link address is <http://www.eia.doe.gov/oiaf/1605/ggrpt/pdf/0573(2006).pdf>). The attached copy was obtained from that link.

8. Attached hereto as Exhibit G is a true and correct copy of the "Full Report" portion of a document issued by the Intergovernmental Panel on Climate Change, entitled "*Climate Change 2007: Synthesis Report*." This document is quoted in paragraph 161 of the Plaintiffs' Compliant in *Native Village of Kivalina*. I obtained the attached copy of this document by going to the website of the Intergovernmental Panel on Climate Change, at the webpage for the Panel's "Fourth Assessment Report" (<http://www.ipcc.ch/ipccreports/ar4-syr.htm>), and

then following the "Full Report" link on that page (the address of the link is <http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf>).

9. Attached hereto as Exhibit H is a true and correct copy of portions of a document issued by the National Academy of Sciences, entitled "*Climate Change Science: An Analysis of Some Key Questions*." This document is quoted in paragraph 157 of the Plaintiffs' Compliant in *Native Village of Kivalina*, and is cited in footnote 36 of that Complaint. That footnote gives the following web address for the document: <http://newton.nap. edu/catalog/10139.html#106>. I entered that web address on my internet browser, and was automatically redirected to <http://books.nap.edu/catalog.php?record_id=10139>, which is a webpage for the "National Academies Press." That webpage, which shows the document "*Climate Change Science: An Analysis of Some Key Questions*," contains a link marked "Full Text" in a section marked "Free Resources." Clicking on that took me to another portion of that same webpage that contained an index of that document, together with associated links to various portions of the document. I followed the link for "Front Matter," which took me to page "i" of the document, and clicked on "Print Page," which then gave me a PDF image of that page (the cover page), which I then downloaded. In the same manner, I followed the link for chapter 3, "Human Caused Forcings," and downloaded each page of that chapter. I then assembled the cover and the various pages of chapter 3 into the single PDF file that is attached as Exhibit H.

I declare under penalty of perjury of the laws of the United States of America that the foregoing is true and correct.

Executed at Los Angeles, California, on June 30, 2008.

/s/ *Daniel P. Collins*
Daniel P. Collins

EXHIBIT A

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF MISSISSIPPI

NED COMER husband of/and BRENDA COMER, ERIC HAYGOOD husband of/and BRENDA HAYGOOD, LARRY HUNTER husband of/and SANDRA L. HUNTER, MITCHELL KISIELWESKI husband of/and JOHANNA KISIELEWSKI, JOSEPH WILLIAMS husband of/and CYNTHIA WILLIAMS, ELLIOTT ROUMAIN husband of/and ROSEMARY ROUMAIN, JUDY OLSON, and DAVID LAIN, ON THEIR OWN BEHALF AND ON BEHALF OF ALL OTHERS SIMILARLY SITUATED, Plaintiffs, vs. MURPHY OIL, U.S.A., UNIVERSAL OIL PRODUCTS, SHELL OIL CORPORATION, CHEVRON U.S.A., INC., CHEVRONTEXACO CORP, EXXONMOBIL CORPORATION, CONOCOPHILLIPS COMPANY, BP PLC, THE AMERICAN PETROLEUM INSTITUTE, OIL AND REFINING ENTITIES 1-100, AMERICAN ELECTRIC POWER CO. INC., SOUTHERN COMPANY SERVICES, INC., TENNESSEE VALLEY AUTHORITY, XCEL ENERGY INC., TXU CORP., CINERGY CORP., RELIANT ENERGY INC., EDISON INTERNATIONAL, E.ON AG, PROGRESS ENERGY INC., AMEREN CORP., SCOTTISH POWER PLC, ENTERGY CORP., ALLEGHENY ENERGY INC., DUKE ENERGY CORP., FIRSTENERGY CORP., DOMINION RESOURCES INC., DTE ENERGY CO., FPL GROUP INC., MIRANT CORP., AES CORP., EI DUPONT DE NEMOURS & CO., HONEYWELL INTERNATIONAL, INC., THE DOW CHEMICAL CO., AMERICAN CHEMISTRY COUNCIL, INC., ARCH	Case No.: 1:05-cv-00436-LTS-RHW THIRD AMENDED CLASS ACTION COMPLAINT (Amendment authorized per Court Order of 23 February 2006, Rec. Doc. No. 75)

COAL, INC., INTERNATIONAL COAL)
GROUP, INC., ALLIANCE RESOURCE)
PARTNERS LP, ALPHA NATURAL)
RESOURCES INC., CONSOL ENERGY)
INC., FOUNDATION COAL HOLDINGS)
INC., MASSEY ENERGY CO.,)
WESTMORELAND COAL CO., PEABODY)
ENERGY CORP., AND NATURAL)
RESOURCE PARTNERS LP,)
)
Defendants.)
)
)

THIRD AMENDED CLASS ACTION COMPLAINT

NOW COME plaintiffs NED COMER husband of/and BRENDA COMER, ERIC HAYGOOD husband of/and BRENDA HAYGOOD, LARRY HUNTER husband of/and SANDRA L. HUNTER, MITCHELL KISIELEWSKI husband of/and JOHANNA KISIELEWSKI, JOSEPH WILLIAMS husband of/and CYNTHIA WILLIAMS, ELLIOTT ROUMAIN husband of/and ROSEMARY ROUMAIN, JUDY OLSON, and DAVID LAIN, through undersigned counsel, appearing herein individually and on behalf of all other persons similarly situated, who file this Third Amended Complaint in accordance with this Honorable Court's order dated 23 February 2006, and aver as follows:

The Oil Company Defendants

1.

Made defendants herein are:

a) Murphy Oil USA, Inc. a Delaware corporation with its principal office at 200 Peach Street, El Dorado, Arkansas 71730, which may be served through its agent CT Corporation System, 645 Lakeland East Drive, Suite 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi that, at all times pertinent hereto, engaged in the exploration,

Case 1:05-cv-00436-LG-RHW Document 136-7 Filed 10/19/2006 Page 3 of 27

development, production, refining, and combustion of oil, petrochemicals, and other carbon based fossil fuels;

b) Universal Oil Products Company (UOP), a Delaware corporation with its principal office at 25 East Algonquin Road, Des Plaines, Illinois 60017-1057, which may be served through its agent Corporation Service Company, 506 South President Street, Jackson, Mississippi 39201, and which is authorized to do and doing business in the State of Mississippi, and which at all times pertinent hereto, supported and provided equipment for the exploration, development, production, refining, and combustion of oil, petrochemicals, and other carbon based fossil fuels;

c) Shell Oil Company, a Delaware corporation with its principal office at 910 Louisiana, Houston, Texas 77002, which may be served through its agent Corporation Service Company, 506 South President Street, Jackson, Mississippi 39201, and which is authorized to do and doing business in the State of Mississippi, and which at all times pertinent hereto, engaged in the exploration, development, production, refining, and combustion of oil, petrochemicals, and other carbon based fossil fuels;

d) Chevron Corp. d/b/a Chevron U.S.A., Inc. and Texaco, Inc., now merged as ChevronTexaco Corp., a Delaware corporation with its principal office at 6001 Bollinger Canyon Road, San Ramon, California 94583, which may be served through its agent CSC of Rankin County, Inc., Mirror Lake Plaza, 2829 Lake Plaza Drive #1502, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi, and which at all times pertinent hereto, engaged in the exploration, development, production, refining, and combustion of oil, petrochemicals, and other carbon based fossil fuels;

e) ExxonMobil Corporation, a New Jersey corporation with its principal office at 5959 Las Colinas Boulevard, Irving, Texas 75039, which may be served through its agent Corporation Service Company, 506 South President Street, Jackson, Mississippi 39201, and which is authorized to do and doing business in the State of Mississippi, and which at all times pertinent hereto, engaged in the exploration, development, production, refining, and combustion of oil, petrochemicals, and other carbon based fossil fuels;

f) BP p.l.c. d/b/a BP Amoco Chemical Company and BP Energy Company (both Delaware corporations), a British corporation with its principal office at 1 St James's Square, London, SW1Y 4PD, UK, which may be served through its agent CT Corporation System, 645 Lakeland East Drive, Suite 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi, and which at all times pertinent hereto, engaged in the exploration, development, production, refining, and combustion of oil, petrochemicals, and other carbon based fossil fuels;

g) ConocoPhillips Company, a Delaware corporation with its principal office at 600 North Dairy Ashford, Houston, Texas 77079, which may be served through its agent CSC of Rankin County, Inc., Mirror Lake Plaza, 2829 Lake Plaza Drive #1502, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi, and which at all times pertinent hereto, engaged in the exploration, development, production, refining, and combustion of oil, petrochemicals, and other carbon based fossil fuels;

h) American Petroleum Institute (API), a Washington D.C. non-profit corporation with its principal office at 118 North Congress Street, Jackson, Mississippi 39201, which may be served through its agent CT Corporation System, 645 Lakeland East Sr. Ste. 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi. API is a trade association whose membership includes the Oil and Refining companies identified herein, and at all times material hereto, had information about the threat of global warming which it failed to disclose to the public; and

i) Oil and Refining Entities 1-100, companies whose names are not currently known but were authorized to do and doing business in the State of Mississippi that, at all times pertinent hereto, engaged in the exploration, development, production, refining, and combustion of oil, petrochemicals, and other carbon based fossil fuels.

The aforesaid defendants (sometimes referred to herein as the "Oil Company Defendants") are liable to plaintiffs and the class of plaintiffs described herein (sometimes referred to collectively as the "Plaintiff Class") for the reasons enumerated *infra*:

<u>The Coal Company Defendants</u>

2.

Also made defendants herein are:

a) American Electric Power Co. Inc., a New York corporation with its principal office at 1 Riverside Plaza, Columbus, Ohio 43215-2373.

b) Southern Company Services, Inc., a Delaware corporation with its principal office at 270 Peach Tree St., Atlanta, Georgia 30308, which may be served through its agent Corporation Service Company, 506 S President St., Jackson, Mississippi 39201, and which is authorized to do and doing business in the State of Mississippi.

c) Tennessee Valley Authority, a Federal corporation with its principal office at 400 W. Summit Hill Dr., Knoxville, Tennessee 37902-1499.

d) Xcel Energy Inc., a Minnesota corporation with its principal office at 800 Nicollet Mall, Minneapolis, Minnesota 55402.

e) TXU Corp., a Texas corporation with its principal office at 1601 Bryan Street, Dallas, Texas 75201-3411, which may be served through its agent CT Corporation System, 645 Lakeland East Sr. Ste. 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi.

f) Cinergy Corp., a Delaware corporation with its principal office at 139 East Fourth Street, Cincinnati, Ohio 45202, which may be served through its agent CT Corporation System, 645 Lakeland East Sr. Ste. 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi.

g) Reliant Energy Inc., a Delaware corporation with its principal office at 1000 Main Street, Houston, Texas 77002, which may be served through its agent Corporation Service Company, 506 S President St., Jackson, Mississippi 39201.

h) Edison International, a California corporation with its principal office at 2244 Walnut Grove Avenue, P.O. Box 999, Rosemead, California 91770.

i) E.ON AG, a German corporation doing business in the United States as Powergen and LG&E Operating Services with its principal office at E On-Platz 1, Düsseldorf, D-40479, Germany.

j) Progress Energy Inc., a North Carolina corporation with its principal office at 410 South Wilmington Street, Raleigh, North Carolina 27601-1748.

k) Ameren Corp., a Missouri corporation with its principal office at 1901 Chouteau Avenue, St. Louis, Missouri 63103.

l) Scottish Power PLC, a British company doing business in the United States as MidAmerican and Pacificorp with its principal office at 1 Atlantic Quay, Glasgow, G2 8SP, UK.

m) Entergy Corp., a Delaware corporation with its principal office at 639 Loyola Avenue, New Orleans, LA 70113, which may be served through its agent James W. Snider, Jr., 308 East Pearl Street, P.O. Box 1640, Jackson, Mississippi 39215-1640, and which is authorized to do and doing business in the State of Mississippi.

n) Allegheny Energy Inc., a Maryland corporation with its principal office at 800 Cabin Hill Drive, Greensburg, Pennsylvania 15601, which may be served through its agent CT Corporation System, 645 Lakeland East Sr. Ste. 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi.

Case 1:05-cv-00436-LTS-RHW Document 1-3 Filed 09/19/2005 Page 6 of 26

o) Duke Energy Corp., a North Carolina corporation with its principal office at 526 South Church Street, Charlotte, North Carolina 28202-1803, which may be served through its agent CT Corporation System, 645 Lakeland East Sr. Ste. 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi.

p) Firstenergy Corp., an Ohio corporation with its principal office at 76 South Main Street, Akron, Ohio 44308, which may be served through its agent CT Corporation System, 645 Lakeland East Sr. Ste. 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi.

q) Dominion Resources Inc., a Virginia corporation with its principal office at 120 Tredegar Street, Richmond, Virginia 23219.

r) DTE Energy Co., a Michigan corporation with its principal office at 2000 2nd Avenue, Detroit, Michigan 48226-1279, which may be served through its agent CT Corporation System, 645 Lakeland East Sr. Ste. 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi.

s) FPL Group Inc., a Florida corporation with its principal office at 700 Universe Boulevard, Juno Beach, Florida 33408, which may be served through its agent CT Corporation System, 645 Lakeland East Sr. Ste. 101, Flowood, Mississippi 39232, and which is authorized to do and doing business in the State of Mississippi.

t) Mirant Corp., a Delaware corporation with its principal office at 1155 Perimeter Center West, Suite 100, Atlanta, Georgia 30338, which may be served through its agent National Registered Agents, Inc., 840 Trustmark Bldg., 248 E Capitol St. Jackson, Mississippi 39201, and which is authorized to do and doing business in the State of Mississippi.

u) AES Corp., a Delaware corporation with its principal office at 4300 Wilson Boulevard, Suite 1100, Arlington, Virginia 22203.

v) Arch Coal, Inc., a Delaware corporation with its principal office at One City Place Drive, Suite 300, St Louis, Missouri 63141.

w) International Coal Group, Inc., a Delaware corporation with its principal office at 200 Ashland Drive, Ashland, Kentucky 44101.

x) Alliance Resource Partners LP, a limited partnership organized under the laws of Delaware, with its principal office at 1717 South Boulder Avenue, Suite 600, Tulsa, Oklahoma 74119.

Case 1:05-cv-00436-LG-RHW Document 136-29 Filed 04/30/2008 Page 8 of 26

y) Alpha Natural Resources Inc., a Delaware corporation with its principal office at One Alpha Place, Abingdon, Virginia 24212.

z) CONSOL Energy Inc., a Delaware corporation with its principal office at 1800 Washington Road, Pittsburgh, Pennsylvania 15241.

aa) Foundation Coal Holdings Inc., a Delaware corporation with its principal office at 999 Corporate Boulevard, Suite 300, Linthicum Heights, Maryland 21090-2227.

bb) Massey Energy Co., a Delaware corporation with its principal office at 4 North 4th Street, Richmond, Virginia 23219.

cc) Westmoreland Coal Co., a Delaware corporation with its principal office at 2 North Cascade Avenue, 14th Floor, Colorado Springs, Colorado 80903.

dd) Peabody Energy Corp., a Delaware corporation with its principal office at 701 Market Street, St. Louis, Missouri 63101-1826.

ee) Natural Resource Partners LP, a limited partnership organized under the laws of Delaware, with its principal office at 601 Jefferson Street, Suite 3600, Houston, Texas 77002.

The aforesaid defendants (sometimes referred to herein as the "Coal Company Defendants") at all times pertinent hereto, engaged in the exploration, development, mining, production and/or combustion of coal and other carbon based fossil fuels. These activities tortiously caused damage to Plaintiffs' property in Mississippi, and are liable to plaintiffs and the class of plaintiffs described herein (sometimes referred to collectively as the "Plaintiff Class") for the reasons enumerated *infra*. Consequently, these defendants are deemed to be doing business in Mississippi and are subject to the jurisdiction of this Court pursuant to Miss. Code Ann. § 13-3-57 (West 2006).

<u>Defendants' Greenhouse Gas Emissions Cause Global Warming</u>

3.

Defendants emit substantial quantities of carbon dioxide, methane, and other substances collectively referred to as "greenhouse gases," increasing the concentration of these gases in Earth's atmosphere.

4.

Increasing the concentration of greenhouse gases in the atmosphere increases the amount of solar energy trapped by Earth's atmosphere, resulting in warmer air and water temperatures.

5.

The Earth's climate has "demonstrably changed" as a result of Defendants' greenhouse gas emissions.[1] The demonstrable changes include higher and rapidly increasing air and water temperatures,[2] rapid sea level rise,[3] melting of arctic, Antarctic, and alpine glaciers,[4] more severe droughts,[5] increased El Niño events,[6] and increased weather-related economic losses.[7]

6.

Defendants' emissions have also substantially increased in frequency and intensity of storms known as hurricanes;[8] effectively doubling the frequency of category four and five hurricanes over the past thirty years.[9]

7.

[1] Robert T. Watson, *et al.*, Intergovernmental Panel on Climate Change, Third Assessment Report: Summary for Policymakers at 4 (2001) (attached as Exhibit 1 and *available at* http://www.ipcc.ch/pub/un/syreng/spm.pdf) (last visited April 18, 2006). The IPCC is the most relied-upon authority on global climate change issues. Their report specifically states that "[t]here is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities. Detection and attribution studies consistently find evidence for an anthropogenic signal in the climate record of the last 35 to 50 years." *Id.* at 5.

[2] "Globally it is very likely that the 1990s was the warmest decade, and 1998 the warmest year, in the instrumental record (1861–2000). The increase in surface temperature over the 20th century for the Northern Hemisphere is likely to have been greater than that for any other century in the last thousand years." *Id.* (internal citations omitted).

[3] *Id.* at 6.

[4] *Id.*

[5] *Id.* at 5.

[6] *Id.* at 6.

[7] *Id.*

[8] Tropical cyclones in the northern hemisphere are referred to as hurricanes and those in the southern hemisphere are referred to as typhoons.

[9] *See* Webster, P.J., G.J. Holland, J.A. Curry, H.-R. Chang, *Changes in Tropical Cyclone Number, Duration and Intensity in a Warming Environment*, SCIENCE, 309 (5742), 1844-1846 (2005) (attached as Exhibit 2 and *available at* http://www.sciencemag.org/cgi/reprint/309/5742/1844.pdf) (last visited April 18, 2006).

One of the most prevalent and problematic greenhouse gases is methane,[10] which the EPA has determined is twenty-one times more effective at trapping atmospheric heat than carbon dioxide.[11]

8.

Defendants release methane into the atmosphere through their mining and drilling operations. A prime example is the venting (intentionally releasing) of methane from oil and gas wells, this represents a significant portion of annual methane emissions in the United States.[12] To the extent that the defendants fail to capture and reinject methane into the ground, and to the extent that methane enters the atmosphere as a direct result of Defendants' mining, transporting, pumping, piping, refining, combustion, and/or distribution activity, Defendants actively increase global warming by releasing methane into the atmosphere.

9.

There has been a perilous increase in the atmospheric concentration of carbon dioxide from approximately 280 parts per million (ppm) at the outset of the Industrial Revolution to 381 ppm during 2005. If current trends continue, including Defendants' willful refusal to employ currently available mitigation technologies, the concentration of carbon dioxide is likely to exceed 700 ppm by the end of this century. According to the Intergovernmental Panel on Climate Change (IPCC), this could lead to global warming of between 1.4 and 5.8°C with concomitant increases in the frequency and magnitude of tropical cyclones (2005's Category 5

---

[10] *See* Intergovernmental Panel on Climate Change, Third Assessment Report: Climate Change 2001, Fig. 2-2 (attached as Exhibit 3).

[11] *See* U.S. EPA, Global Warming Potentials and Atmospheric Lifetimes (attached as Exhibit 4 and *available at* http://www.epa.gov/nonco2/econ-inv/table.html) (last visited April 18, 2006).

[12] *See* Government Accountability Office, Natural Gas Flaring and Venting: Opportunities to Improve Data and Reduce Emissions at 18 (July 2004) (attached as Exhibit 5 and *available at* http://www.gao.gov/new.items/d04809.pdf) (last visited April 18, 2006).

Hurricanes Katrina, Rita, Emily, and Wilma as examples) and other severe weather conditions, plus damage to many natural ecosystems.

10.

Defendants have engaged in activities which have produced the greatest source of the greenhouse gases that cause Global Warming.

11.

Despite warnings from scientists and governmental agencies about the adverse effects of their activities on the environment in general and global warming in particular, the Defendants have knowingly and willfully continued to engage in the activities which cause Global Warming. Further, the Defendants have taken no action to mitigate the severe consequences of their activities on human health and the environment, despite the existence of currently available mitigation technologies which the Defendants refuse to employ.

12.

There is now an overwhelming consensus within the scientific community that the planet Earth is getting warmer, this temperature increase is a direct result of the illegal and tortious conduct of these defendants, and the problem is getting worse. There is now more carbon dioxide in the Earth's atmosphere than at any other point in the past 650,000 years.

Defendants' Actions Were a Proximate and Direct Cause of the Increase in the Destructive Capacity of Hurricane Katrina

13.

On 29 August 2005 Hurricane Katrina struck the Mississippi Gulf Coast causing extensive and catastrophic damages by force of wind and related weather events all of which caused loss of life and property as more fully described herein.

14.

Upon striking the Mississippi Gulf Coast, Hurricane Katrina spawned tornados, mesovortices, wind shear, a massive storm surge and related weather events which caused damage, death and injury to persons, homes, businesses and other property interests across the State of Mississippi.

15.

Prior to striking the Mississippi Gulf Coast, Hurricane Katrina had developed into a cyclonic storm of unprecedented strength and destruction, fueled and intensified by the warm waters and warm environmental conditions present in the Atlantic Ocean, Caribbean Sea, and the Gulf of Mexico, all of which were a direct and proximate result of the defendants' greenhouse gas emissions.

<u>This Court Has Jurisdiction and Venue is Proper</u>

16.

This Court has jurisdiction to hear this matter pursuant to 28 U.S.C. § 1332 because it involves a dispute between citizens of different states and the matter in controversy exceeds $75,000.

17.

Venue is proper in the Southern District of Mississippi pursuant to 28 U.S.C. §§ 1391-92 because a substantial part of the events giving rise to these claims occurred in this District and a substantial part of property that is the subject of the action is situated in this District.

18.

This case presents discrete and justiciable questions (whether Defendants' emissions of greenhouse gasses caused damage to Plaintiffs' property, and, if so, the extent of those damages). There are manageable standards for resolving the controversy (common law claims of nuisance, unjust enrichment, negligence, civil conspiracy, and intentional torts including fraudulent

misrepresentation and concealment and trespass, with all such causes of action being cognizable under the laws of the State of Mississippi and appropriate legal regimes imported by the applicable choice of law rules). These issues are neither textually committed to a coordinate political department nor do they implicate the primary authority of the executive or legislative branch.[13]

19.

Plaintiffs do not ask this Court to regulate Global Warming or change national global warming policy. Instead, Plaintiffs seek legal redress for the damages caused by these Defendants. To deny Plaintiffs that opportunity would violate their fundamental and Constitutional rights to have access to justice (embodied in the common law, Magna Carta, the 5th, 7th, 9th, and 14th amendments to the United States Constitution, and Art. 3 of the Mississippi Constitution).

20.

To the extent that this petition raises political issues, those issues are subordinant to the plaintiffs' physical and monetary damages. Furthermore, although Global Warming causes tremendous damage to the environment, public health, and public and private property every year, there is a dearth of meaningful political action in the United States to address Global Warming problems.[14] Thus, to the extent that the political process has failed to provide people

---

[13] It is also evident that Article III resolution is the only viable choice here as the branches of government authorized by Articles I and II of the U.S. Constitution have refused to act, either by virtue of corruption of the process or the tortious and illegal conduct of these Defendants in misleading and manipulating those branches of government into inaction and taking the wrong actions in those instances where they have acted.

[14] This is due, at least in part, to the substantial gap in political power between the people who cause global warming (a relatively concentrated group of powerful, well-connected, and wealthy companies), and the interests most affected by global warming (including the Plaintiffs in this case).

harmed by global warming with means to recover for their injuries, the Courts must execute their Constitutional mandate embodied in Article III of the U.S. Constitution.

Unjust Enrichment

21.

There have been significant increases in the price of gasoline, diesel fuel, jet fuel, natural gas and other end-use petrochemicals to which the Oil Company Defendants have fraudulently attributed, at least in part, to a lack of domestic oil refining capacity and the cost of compliance with domestic environmental regulations. These artificially inflated prices, justified by patent untruths, constitute illegal profiteering. This profiteering on the part of the Oil Company Defendants has (through their manipulation of gasoline, diesel fuel, jet fuel, natural gas and other petrochemicals prices) resulted in billions of dollars of tortiously manufactured profits during the same period in which they failed to employ state of the art technological and commercially viable options to reduce their production of these environmentally harmful greenhouse gases.

22.

In addition to the foregoing tortious price manipulation (ironically under the guise of increased costs caused by Hurricane Katrina, a classic example of fraud in the offing crying out for application of estoppel), the Oil Company Defendants have continued to raise the price of gasoline beyond genuine market-driven levels, all of which has resulted in such record-breaking profits that even Congress was forced to initiate inquiry.[15] For example, Shell Oil Company alone raised its price of gasoline 6 times over a ten day period immediately following the landfall

---

[15] This Congressional inquiry has predictably resulted in no Article II action to stop the profiteering. Perhaps the most telling detail of these hearings was the fact that the investigating Senate Committee refused to require that the oil company executives be sworn before giving their "testimony."

of Hurricane Katrina.[16] Defendants' concerted activity continues to force gasoline (and the other aforementioned products') prices above competitive market value. This activity constitutes price gouging and other market manipulation in violation of law by which the Oil Company Defendants have been unjustly enriched at the expense of members of the Plaintiff Class and other consumers.[17] Certain members of the Oil Company Defendant Class have been sued and/or criminally investigated for price gouging by the Attorneys General of New Jersey, Florida, and other states, reminiscent of the States taking action where the Federal Government would not.

23.

The Oil Company Defendants have committed multiple violations of federal and state environmental regulations and laws. These violations have further harmed the environment and are increasing the production of greenhouse gases and the effects of Global Warming (*e.g*. rising ocean temperatures, increases in tropical cyclone frequency and strength, and rising sea levels). In violating various environmental laws, Defendants have wrongfully generated tremendous profits at the expense of the Plaintiffs, the public, human health and the environment.

Civil Conspiracy and Aiding and Abetting

24.

The American Petroleum Institute (API) and its constituent members have been aware for many years of the dangers posed by the build-up of the greenhouse gasses and the direct

[16] Juan Gonzalez, *Shell Game at Gas Stations Pays Big*, NEW YORK DAILY NEWS, Sept. 8, 2005.

[17] In other words, Defendants are holding onto profits to which they are not lawfully entitled. *See Fordice Const. Co. v. Cent. States Dredging Co.*, 631 F. Supp. 1536, 1538-39 (S.D. Miss. 1986) ("Mississippi law provides that, in an action for unjust enrichment, 'the plaintiff need only allege and show that the defendant holds money which in equity and good conscience belongs to the plaintiff.' The requirements of proof of unjust enrichment are neither technical nor complicated and, [Plaintiffs] can state a claim against Defendants on the basis that [Defendants] were unjustly enriched because they received the profits…they should not have been permitted to [receive].").

Case 1:05-cv-01413-SRB Document 1 Filed 06/10/2006 Page 15 of 27

relationship to the activities of their members who are the Oil Company Defendants. Despite this knowledge, the API and its members, the Oil Company Defendants, have collectively and unlawfully disseminated misinformation about the relationship between the activities of its members and Global Warming.

25.

The API and other Oil Company Defendants have engaged in concerted financial activity—far in excess of $1 million—in furtherance of a tortious civil conspiracy to "reposition global warming as theory rather than fact."[18] In addition, "from 2001 to 2003, ExxonMobil [alone] donated more than $6.5 million to organizations that attack mainstream climate science and oppose greenhouse-gas controls."[19] All of this activity has been part of a concerted and tortious effort to intentionally decrease public awareness and divert public policy activity away from the real dangers associated with Global Warming and the known need to restrict the emission of greenhouse gasses.[20]

26.

[18] Sandi Doughton, *The Truth About Global Warming*, THE SEATTLE TIMES, Oct. 9, 2005 (attached as Exhibit 6) (citing "memos first uncovered by former Boston Globe journalist Ross Gelbspan").

[19] *Id.*

[20] Specific evidence of this conspiratorial conduct is documented by a 1998 New York Times article (attached as Exhibit 7), in which API, Exxon, Chevron and The Southern Company admit their efforts (via lucrative financing and admitted targeting of mercenary "scientists") to intentionally deceive, mislead and perpetrate a fraud upon these Plaintiffs, the public and the government—all with the specific intent to continue to be unjustly enriched at the expense of the public, human health and the environment.

This conspiracy[21] delayed and otherwise interfered with individual and government action to address Global Warming, and consequently contributed to Plaintiffs' injuries enumerated *supra* and *infra*.

27.

In financing and otherwise orchestrating the effort to suppress genuine Global Warming science and divert public policy activity away from greenhouse gas regulation, Defendants aided and abetted this illegal conduct by knowingly providing substantial assistance to persons engaged in wrongful conduct, all of which contributed to the loses and injuries sustained by the Plaintiffs and the Plaintiff Class.

<u>Public and Private Nuisance</u>

28.

Defendants have willfully, wrongfully, unreasonably, unwarrantably and unlawfully used their property and conducted their business to mine, drill, manufacture, release, vent, and/or combust substances in such a way as to produce massive amounts of greenhouse gasses.

29.

The Defendants' behavior and greenhouse gas emissions result in material annoyance, inconvenience, discomfort, injury, and/or hurt to the public and the Plaintiffs in particular, as described more fully *infra*.

30.

[21] A stated goal of this illegal conspiracy was to prevent government action by disseminating false information which would preclude Senate ratification of the Kyoto Treaty. *Id.* (noting that among the conspirators' goals was "a campaign to recruit a cadre of scientists who share the industry's views of climate science and to train them in public relations so they can help convince journalists, politicians and the public that the risk of global warming is too uncertain to justify controls on greenhouse gases like carbon dioxide").

The Defendants' greenhouse gas emissions have contributed to sea level rise,[22] which has a number of severe consequences including, but not limited to the following:

a. Direct loss of private property as land is subsumed under rising sea levels and destroyed by saltwater intrusion.

b. Loss of the use and quiet enjoyment of private property caused by rising sea levels, saltwater intrusion, increased water temperatures, increased tropical storm activity, loss of habitat used for hunting and fishing and other recreation, and numerous other forms of property damage.

c. Loss of the use and enjoyment of public property caused by the subsumption and erosion of public beaches.

d. Loss of the use and enjoyment of public trust resources caused by subsumption of and saltwater intrusion into habitat for fish and wildlife. The destruction of this habitat reduces its utility for hunters, fisherman, birdwatchers, boaters, campers, and other recreationists.

e. Increased risk of property damage and loss as a result of hurricane activity in the Gulf of Mexico. Coastal wetlands and beaches act as a natural buffer and barrier to cyclonic storms in the Gulf of Mexico, and to the extent that they are being destroyed by rising sea levels, coastal residents have become much more prone to storm damage.

Trespass

31.

[22] Robert T. Watson, *et al.*, Intergovernmental Panel on Climate Change, Third Assessment Report: Summary for Policymakers at 6 (2001) (previously attached as Exhibit 1).

The Defendants' behavior and greenhouse gas emissions caused saltwater, debris, sediments, hazardous substances, and other materials to enter and remain on Plaintiffs' and Plaintiff Class's property.

32.

The entry of these materials caused physical harm and destruction to Plaintiffs' and the Plaintiff Class's property.

Negligence

33.

The Defendants had and continue to have a duty to conduct their business in such a way as to avoid unreasonably endangering the environment, public health, and public and private property, as well as the citizens of the State of Mississippi.

34.

The Defendants breached their duties by emitting substantial quantities of greenhouse gases, knowing that such emissions would unreasonably endanger the environment, public health, and public and private property interests.

35.

The Defendants' greenhouse gas emissions contributed to global warming, which caused the Plaintiffs' and Plaintiff Class's injuries.

Fraudulent Misrepresentation and Concealment

36.

Defendants actively engaged in Public Relations and Public Policy campaigns to divert the public's attention from the dangers posed by Global Warming.[23]

[23] Examples of this are found in the activities discussed in Exhibits 6 and 7.

37.

Supported by "science" they knew to be false and misleading, and which was financed and manufactured by the very same revenues which were illegally generated by the activities set forth in paragraphs 21-23, Defendants made false and material misrepresentations about the existence of Global Warming, the extent of Defendants' greenhouse gas emissions and the threats Global Warming posed to public health, the environment and these Plaintiffs.

38.

Defendants made these materially false statements intending to persuade the Federal Government and state governments to refuse to regulate the emission of greenhouse gases, and to seduce the general public into consuming more of Defendants' products.

39.

At the time Defendants made these materially false statements, the public and State and Federal Governments did not know that Defendants' statements were false. The State and Federal Governments, acting upon Defendants' statements and representations, refused to regulate greenhouse gas emissions. The public had a right to rely and did rely upon Defendants' statements, and continued to consume products in ways that increased Global Warming, all of which resulted in continued and increased profits to the Defendants. Plaintiffs' and Plaintiff Class's injuries were proximately caused by that reliance.

Injuries

40.

As a direct and proximate result of the activities of the Defendants (including their production of environmentally harmful by-products), there has been a marked increase in global temperature which, in turn, produced the conditions whereby a storm of the strength and size of

Hurricane Katrina would inevitably form and strike the Mississippi Gulf Coast resulting in extensive death, injury and destruction. As a result thereof, the Plaintiff Class has sustained the following non-exclusive damages:

a) Loss of property;

b) Loss of the use and enjoyment of their property;

c) Loss of their business and/or income;

d) Incurred clean-up expenses, past, present and future;

e) Disruption of the normal course of their lives;

f) Loss of loved ones;

g) Mental anguish and emotional distress;

h) Personal injury;

i) Hedonic damages;

j) Litigation, Expert Witness Fees, and Court costs; and

k) Such other elements of damage as may be shown at trial.

41.

In addition to all other relief sought against the Defendants, the Plaintiffs and Plaintiff Class seek and are entitled to receive punitive damages from the Defendants for their conduct which amounts to willful indifference, extreme recklessness, gross negligence and an illegal conspiracy to prevent dissemination of scientific information regarding the specific hazards created by Global Warming.

The Chemical Manufacturer Defendants

42.

Also made defendants are:

a) EI DuPont de Nemours & Co., a Delaware corporation with its principal office at 1007 Market Street, Wilmington, Delaware 19898 which may be served through its agent CT Corporation System, 645 Lakeland East Drive, Suite 101, Flowood, Mississippi 39232.

b) Honeywell International, Inc., a Delaware corporation with principal office at 101 Columbia Road, Morris Township, New Jersey 07962 which may be served through its agent Corporation Service Company, 506 South President Street, Jackson, Mississippi 39201.

c) The Dow Chemical Co., Inc., a Delaware corporation with its principal office at 2030 Dow Center, Midland, Michigan 48674 which may be served through its agent CT Corporation System, 645 Lakeland East Drive, Suite 101, Flowood, Mississippi 39232.

d) American Chemistry Council, Inc., a New York Corporation and trade association with its principal office at 1300 Wilson Blvd., Arlington, Virginia whose membership includes members of the Chemical Manufacturer Defendants, and who had information about the threat of global warming which it failed to disclose to the public.

These Defendants, at all material times, engaged in the production and release of compounds known as "Halocarbons." These activities tortiously caused damage to Plaintiffs' and Plaintiff Class's property in Mississippi, and are liable to plaintiffs and the class of plaintiffs described herein (sometimes referred to collectively as the "Plaintiff Class") for the reasons enumerated *infra*. Consequently, these defendants are deemed to be doing business in Mississippi and are subject to the jurisdiction of this Court pursuant to Miss. Code Ann. § 13-3-57 (West 2006).

43.

These defendants, which comprise the "Chemical Manufacturer Defendants", are liable to the Plaintiffs and Plaintiff Class for the following reasons:

Halocarbons

44.

The Chemical Manufacturer Defendants manufacture a class of chemicals known as "halocarbons" which include fluorocarbons ("FCs"), chlorofluorocarbons ("CFCs"), hydrofluorocarbons ("HFCs"), and hydrochlorofluorocarbons ("HCFCs").

45.

These chemicals are entirely artificial and do not exist in nature. They are also powerful heat-trapping agents—a pound of halocarbon gas is tens of thousands of times more effective at trapping heat than an equivalent amount of carbon dioxide.[24] In addition, halocarbons can persist in the atmosphere thousands of times longer than either carbon dioxide or natural gas.[25] Thus, while halocarbon emissions are relatively small by volume, their impact on the global warming effect is enormous and long-lasting.[26]

46.

In manufacturing these dangerous greenhouse gases, the Chemical Manufacturer Defendants substantially contribute to the global warming effects described *supra*.[27] As such they are liable to the Plaintiffs and Plaintiff Class for the same damages described *supra*.

47.

The Plaintiff Class further seeks to have this matter certified and maintained as a class action as to a class of plaintiffs who were residents of and/or property owners in the State of Mississippi who suffered loss and harm as a result of Hurricane Katrina. Plaintiffs meet the class-certification requirements of Fed. R. Civ. P. Rule 23 because:

---

[24] *See* U.S. EPA, Global Warming Potentials and Atmospheric Lifetimes (previously attached as Exhibit 3) (noting that the global warming potential (GWP) of halocarbons ranges from 140 to 23,900—that is, they trap between 140 and 23,900 times as much heat as carbon dioxide on a per-particle basis).

[25] *Id.* (noting that some halocarbons persist in the atmosphere for 50,000 years)

[26] *See* U.S. EPA, In Brief: The U.S. Greenhouse Gas Inventory at 7 (April 2005) (noting that in 2003 halocarbons amounted to the equivalent of 137 trillion grams of carbon dioxide emissions) (attached as Exhibit 8 and *available at* http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html) (last visited April 18, 2006).

[27] *See* Intergovernmental Panel on Climate Change, Third Assessment Report: Climate Change 2001, Fig. 2-2 (previously attached as Exhibit 3).

a) the class of Plaintiffs harmed by Defendants' actions is so numerous that joinder of all members is impracticable;

b) there are questions of law or fact common to the class;

c) the claims or defenses of the representative parties are typical of the claims or defenses of the class;

d) the representative parties will fairly and adequately protect the interests of the class;

e) if Plaintiffs pursued claims against defendants individually, it would create a risk of inconsistent or varying adjudications and might establish incompatible standards of conduct for Defendants;

f) adjudication in this matter will, as a practical matter, be dispositive of other Plaintiffs' claims who are not parties to this adjudication, and a decision in this case might substantially impair or impede their ability to protect their interests; and

g) questions of law and fact common to the members of the class predominate over any questions affecting only individual members, and therefore a class action is superior to other available methods for the fair and efficient adjudication of the controversy.

WHEREFORE, PREMISES CONSIDERED, plaintiffs pray for relief and judgment against the Oil Company Defendants as follows:

a) for such damages as are reasonable in the premises for all losses sustained by plaintiffs, including litigation expenses, expert witness fees, legal interest, attorneys' fees and all costs of this proceeding;

b) certification of this matter as a class action for the class of plaintiffs who were residents of and/or property owners in the State of Mississippi who suffered loss and harm as a result of Hurricane Katrina;

c) punitive and exemplary damages for the willful, wanton and grossly negligent conduct of the Defendants; and

d) such other and further legal and equitable relief as this Court deems just and proper.

WHEREFORE, PREMISES CONSIDERED, plaintiffs pray for relief and judgment against the Coal Company Defendants as follows:

a) for such damages as are reasonable in the premises for all losses sustained by plaintiffs, including litigation expenses, expert witness fees, legal interest, attorneys' fees and all costs of this proceeding;

b) certification of this matter as a class action for the class of plaintiffs who were residents of and/or property owners in the State of Mississippi who suffered loss and harm as a result of Hurricane Katrina;

c) punitive and exemplary damages for the willful, wanton and grossly negligent conduct of the Defendants; and

d) such other and further legal and equitable relief as this Court deems just and proper.

WHEREFORE, PREMISES CONSIDERED, plaintiffs further pray for relief and judgment against the Chemical Manufacturer Defendants as follows:

a) for such damages as are reasonable in the premises for all losses sustained by plaintiffs, including litigation expenses, legal interest, attorneys fees and all costs of this proceeding;

b) certification of this matter as a class action as to the class of plaintiffs who were residents of and/or property owners in the State of Mississippi who suffered loss and harm as a result of Hurricane Katrina;

c) punitive and exemplary damages for the willful, wanton and grossly negligent conduct of the Chemical Manufacturer Defendants; and

d) such other and further legal and equitable relief as this Court deems just and proper.

Respectfully submitted this 18th day of April, 2006.

s/ F. Gerald Maples
F. Gerald Maples, T.A. (MSB No: 1860)
Carlos A. Zelaya, II (*pro hac vice*: 44645)
MAPLES & KIRWAN, L.L.C.
902 Julia Street
New Orleans, LA 70113
Telephone: (504) 569-8732
Facsimile: (504) 525-6932

Stephen M. Wiles (*pro hac vice*: 44113)
Randall A. Smith (*pro hac vice*: 43700)
SMITH & FAWER, L.L.C.
201 St. Charles Ave., Suite 3702
New Orleans, LA 70170
Telephone: (504) 525-2200
Fax: (504) 525-2205

Timothy W. Porter (MSB No: 9687)
PORTER & MALOUF
825 Ridgewood Rd
Ridgeland MS 39157
Telephone: (601) 957-1173
Fax: (601) 957-7366

CERTIFICATE OF SERVICE

I hereby certify that I have on this the 18 day of April, 2006, electronically filed the foregoing with the Clerk of Court using the CM/ECF system which will send notification of this filing to the following:

Richard L. Forman	rforman@fpwk.com
Mary S. Johnson	msj@JGMcLaw.com
David L. Martindale	dmartindale@hortmanharlow.com, jniemeyer@hortmanharlow.com

And further certify that I have caused to be deposited in the U.S. mail a copy of such pleading, postage prepaid to the following Non-ECF parties:

Chevron Corporation
Attn: Charles A. James
6001 Bollinger Canyon Rd.
San Ramon, CA 94583, U.S.A.

Murphy Oil USA
Attn: James E. Baine
Murphy Oil Corporation
200 Peach Street
P.O. Box 7000
El Dorado, AR 71731-7000

Universal Oil Products Co
Attn: Michael Van de Kerckhove
25 East Algonquin Road
Des Plaines, IL 60017-5017

Service of added defendants will be as required by Rule 4 of the Federal Rules of Civil Procedure.

s/ F. Gerald Maples
F. Gerald Maples

EXHIBIT B

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF MISSISSIPPI
SOUTHERN DIVISION

NED COMER, ET AL PLAINTIFFS

V. CIVIL ACTION NO: 1:05CV436-LG-RHW

MURPHY OIL, U.S.A., ET AL DEFENDANTS

TRANSCRIPT OF HEARING ON DEFENDANTS' MOTIONS TO DISMISS

BEFORE HONORABLE LOUIS GUIROLA, JR.
UNITED STATES DISTRICT JUDGE

AUGUST 30, 2007
GULFPORT, MISSISSIPPI

COURT REPORTER:

TERI B. NORTON, RMR, FCRR
2012 15TH STREET, SUITE 814
GULFPORT, MISSISSIPPI 39501
(228) 563-1740

373

APPEARANCES:

REPRESENTING THE PLAINTIFFS:

F. GERALD MAPLES, ESQUIRE
ALEXANDER J. WILLIAMSON, ESQUIRE
CARLOS A. ZELAYA, ESQUIRE
STEPHEN M. WILES, ESQUIRE
F. GERALD MAPLES, PA
902 JULIA STREET
NEW ORLEANS, LOUISIANA 70113

REPRESENTING THE DEFENDANTS:

SCOTT L. WINKELMAN, ESQUIRE
KATHLEEN TAYLOR SOOY, ESQUIRE
TRACY A. ROMAN, ESQUIRE
CROWELL & MORING
1001 PENNSYLVANIA AVENUE, N.W.
WASHINGTON, DC 20004-2595

ROBERT D. GHOLSON, ESQUIRE
BURR & FORMAN
THE HERITAGE BUILDING
401 EAST CAPITOL STREET, SUITE 100
JACKSON, MISSISSIPPI 39201

THE COURT: The matter scheduled this morning is in cause number 1:05cv436. The case is styled Ned Comer, et al versus Murphy Oil U.S.A., et al. This matter is scheduled for an oral argument hearing on a series of motions to dismiss upon which the Court today will concentrate or will hear argument regarding one issue and one issue only, and that is the question of whether or not this Court has the jurisdiction over the claims made by the plaintiffs. In particular I have asked the attorneys to focus on the issue of standing and political question. I am given to understand that on behalf of the plaintiffs that Mr. Maples, Gerald Maples, you will be speaking on behalf of the plaintiffs? Is that correct?

MR. MAPLES: Yes, sir.

THE COURT: And Mr. Winkelman, you will be speaking on behalf of the defendants?

MR. WINKELMAN: Yes, Your Honor.

THE COURT: I think it would be helpful to the court reporter, and it would be helpful to me as well, if we went around the room, starting with you, Mr. Maples, and if we went around and you would all identify yourselves and identify who you represent.

MR. MAPLES: Gerald Maples for the plaintiffs.

MR. WILLIAMSON: Alex Williamson on behalf of the plaintiffs.

MR. WILES: Stephen Wiles representing the

plaintiffs.

MR. ZELAYA: Carlos Zelaya on behalf of the plaintiffs.

MR. WINKELMAN: Scott Winkelman, Judge, for the Coal Company defendants.

MR. GHOLSON: Bob Gholson, Coal Company defendants.

MS. SOOY: Kathleen Sooy for the Coal Company defendants.

MS. ROMAN: Tracy Roman for the Coal Company defendants.

THE COURT: Very well. Thank you. I have chosen as a format, and I think that since we are concentrating on jurisdictional issues, I have chosen as a format approximately 20 minutes argument per side, and since the defendants bring the motion, they will speak first. I would think that the best approach would be to allow you approximately 15 minutes within which to begin. Mr. Maples, I will hear from you afterward, and then I will give you about five minutes for rebuttal.

I take this matter very seriously. I have read many, many motions, many, many briefs, and what little case authority there is available for the Court on these issues. So while that may not seem like a lot of time to argue a very important matter, the Court is somewhat educated on the issues. And in any event, these arguments will, in all likelihood, be good practice because I have no doubt that whatever ruling the Court

issues here will have to be the subject of review by an appellate court. Mr. Winkelman, I will hear you on your motions. And if I interrupt with a question, it will not be counted against you.

MR. WINKELMAN: Well, good morning, Judge, and thank you so much for hearing us on these two issues. I do think we can get the job done in the time that you have suggested. One reason I say that, Judge, is because, as Your Honor is aware, what the Supreme Court has told us is that the doctrines you have asked about today are practical. We apply straightforward tests, in one case under *Baker v. Carr*, in one case under *Allen v. Wright* and *Lujan*, to complaints. It is rather as simple as that.

I will start, Judge, by suggesting the interplay and fundamental relationship between the two doctrines, Judge, that you have asked us to talk about today because they are so, not just fundamental to our system of justice but so fundamentally interrelated. Both, Judge, as you know, go to power of a Court, both moreover are about the separation of powers in our system of government. As I said, both doctrines are very practical, straightforward tests, not always easy to apply but at least the tests themselves are straightforward. Both doctrines, Your Honor, impose each and every burden upon the plaintiff and upon the complaint that the plaintiff has given the Court. Both are questions of law to be decided at the

threshold because, after all, they do go to the power's authority to adjudicate, as Your Honor mentioned at the outset. Both, I would say, and the Courts do, are, in a sense, about humility. It is one of the wonderful things of our system, aspects of our system of government that what you have withstanding in political question are Courts recognizing what they can do, and times when they can't solve problems. Both in this case are important because what they seek from the Court I would say is a ruling that never before has happened, an unprecedented ruling. No Court has found itself able to adjudicate the issues underlying the Comer complaint, that is, the policy issues about global warming, and no Court ever, to my knowledge, has found a private party in our system to have Article III standing in the context of a global warming scenario. So that is how, in my humble opinion, the two interrelate.

Let me turn directly to standing itself, and then I will move along, Judge, to political question. In terms of standing, as I said, we are talking about limits fundamental from the beginning of our experience, fundamental to the separation of powers, what courts can and cannot do, and the task for a judge when faced with a standing issue, constitutional standing, that is, is to simply look at the complaint, in this case the third amended Comer complaint, and apply to it a three-part test that has been given us by the

Supreme Court in *Allen v. Wright*, and in the *Lujan* case, those three prongs being, is there injury in fact adequately alleged in the complaint, is there traceability that is a credible, plausible link between the conducts alleged, in this case I would say lawful conduct of the Coal Company defendants, a link between conduct and between the injury, the harm, at issue, and, finally, redressability, which is another kind of a link. There you are focusing on the link between the injury alleged, again in this case, property damage, and the relief being sought in this case, mostly monetary damages.

As you know, Judge, we have placed all three at issue on behalf of our clients. You also know that we have focused most of our energy on the final two prongs, which in many cases overlap. In this case we would say they overlap, and fundamentally they are about causation, about conjecture, and about remoteness.

The reason we focus there, Judge, is the reason Judge Senter seemed to focus on that when this case was before him in February of 2006, and forgive me for telling you things you know, but what the Court hinted at at that early stage was a fear about the daunting, he called it, causation dilemma faced by this case involving global warming. We think Judge Senter foreshadowed something exactly right, looking at a complaint that materially hasn't improved on that issue. The fact remains, in terms of traceability, that when you ask yourself

what is the link, what is the link between an emission in the complaint, a link between an emission of a greenhouse gas and an injury, a property damage to a specific parcel in the State of Mississippi, you don't know where to go. The complaint tells us not how to get from that one dot to the other. Indeed, what the complaint tells us, and we have emphasized this in our papers, taking the plaintiffs' own word for it, are eight or nine links in that chain, getting from this emission of a gas by some or one of the billions and billions of emitters of carbon dioxide gases, including everybody in this court, by the way, and 123 Johnson Street in Mississippi. That is a specifically harmed piece of property. That is the fundamental traceability problem, we think, in this case. And we don't need to speculate about that at this stage because the complaint, by very fine lawyers, has done a good job of fleshing out exactly that causal chain, and what we know for certain is that there is no way to shorten that chain or to strengthen the links. Why do we know that? Because global warming is what it is. It is a global phenomenon, as its name suggests. There is no shortcut to get from this emission, a particular harm -- misconduct, that is, alleged misconducts, in a particular piece of property, and never could be.

That, in essence, Judge, is our position on the traceability requirement from the Supreme Court on standing, and as you know, we then turn to redressability, which in many

cases like this is interwoven with the traceability problem in order to redress a property damage as alleged in the third amended complaint. What would a Court have to do to get from here to there? What would the actual adjudication look like? Well, once again, what it would look like is all of the same causation problems.

What we have here are tort claims. In a sense, this is Tort Law 101. Duty, just as an example, is at the center as an element of every claim in this case. For Your Honor and a jury to determine duty more so, Your Honor, that being a question of law, we would have to decide what is the right level, what is an acceptable level of emissions in a world in which, after all, again, my clients have engaged in nothing but lawful activity. About that there is no dispute. So to litigate the duty question, we would have to find, the judge would have to find that some emissions are acceptable and some are tortious. Well, here we go again. We have the same causal link problems, and compounding that problem you have political question problems. And while I will get to political question next, this is the place, redressability is the place where the two doctrines intersect, because to decide duty, to decide that certain emitters should shoulder burdens related to global warming, to decide who does and who doesn't pay, we are deciding, a judge would be deciding precisely the issues that the elected branches of our government are deciding as we

speak, and to some extent already have decided.

So, again, I will get back to political question, but redressability here folds in quite neatly with the political question issues that underlie the tort claims in this case, and the Supreme Court law sees that interrelationship, and when the chain went to redress a harm, you have to stretch through a causation quagmire, the Courts find no redressability.

Judge, finally, on standing, what I would say is, another thing that we know for sure, which is that no amount of repleading, modifying of the complaint, can fix this problem. We know that, for starters, because the Supreme Court does not allow that. The Supreme Court, as you know, says this is about power, it is about a, quote-unquote, discriminating analysis of the complaint itself and whether on that complaint, the third amended complaint, the plaintiffs have established standing.

The fourth amended complaint, the one that has not been accepted, doesn't modify the causal chain allegations, and this case does not modify the theories of redressability, and nor could it, because, again, this case is about what is fundamental, what is inherent about a global phenomenon, that is, global warming.

So, Judge, we think if we simply apply the practical test directly laid out by the Supreme Court, the right conclusion is that this case cannot be in this court because there is no Constitutional standing.

Let me turn, if I can, Judge --

THE COURT: Before we move away -- you are moving into the political question arena. Before we move away from the standing question, so I can trim the bush, if you will, if you will allow me, although you have placed in issue all three elements, all three of the standing elements, do you concede the first of those elements, and that is that the plaintiff, or plaintiffs, have suffered an injury in fact?

MR. WINKELMAN: Thank you, Judge. We do not concede that. You are exactly right that our papers have focused on traceability and redressability. We do not believe that the complaint meets Supreme Court obligations to allege a concrete injury. Having said that, we have turned our focus on the fundamental causation and remoteness problem.

THE COURT: Thank you. Go ahead.

MR. WINKELMAN: Thank you. Let's turn to, then, if I might, to political question, which again is a limit on judicial power. It once again is a doctrine about prudence, about humility, and about when Courts ought not take on cases because our elected officials, Congress and the President, are and have. And, again, here we are blessed by a very straightforward test. *Baker v. Carr*, in 1962, identified the six prongs that, if any is met, finds the case to be a political question. And what in a sense I would say, Judge, is most important about teachings on political question, and again

I am quoting from the Supreme Court, is that there can be no semantic cataloguing. You can't look at the name of the cause of action and decide yea or nay. What the Supreme Court teaches us is that you have to dig lower. The question is whether to resolve the trespass claim in this case, the nuisance claim in this case. Would you have to wind up getting bound up in questions that are meant for our political branches?

So, Your Honor, in our briefs we have focused specifically on the *Baker v. Carr* prongs that render this case nonjusticiable political questions, and in a sense I would say, Judge -- and I have never seen a case in this jurisprudence like this. What makes this easy is the plaintiffs' own complaint. The plaintiffs' complaint, the third amended complaint and all of its predecessors, say, the Article I and Article II components of our national government are dealing, are taking action on global warming, the issues underlying the claims here. Their complaint in their complaint is that that action is not the action that some might want, so they are coming to a Court as a refuge, as a different way of achieving the relief and answering the political questions, the policy -- making the policy choices that Congress and the President already have made and are continuing to make every day.

So taking the plaintiffs at their own word, this is the quintessential political question case. Specifically, Judge, I

would refer you to footnote 13 and 14 in the complaint. It has nothing but illustrations of where the plaintiffs emphasize the political nature and the political activity of our elected branches of the government.

Judge, the core reasons why we think this case could only be a political question case are two. First is the nature of global warming itself. It surprises nobody in this room, and the title suggests global warming is a global problem. It knows no borders. It is not local, like, for instance, cases dealing with floods, dealing with erosion. On flood and erosion cases, of course sometimes the Federal Government gets involved, and yet usually political question doctrines don't apply, but it is the nature of global warming, as Judge Sentelle once said, affecting humanity at large, that calls out for comprehensive decisions by our political branches. That is the reason one. The reason two, Judge, is what I just alluded to. It is the very nature and degree of political action. It is not as if we just have a big issue named global warming. We have a big issue being dealt with comprehensively by our political branches, and that is not just a today phenomenon, as you know. For at least three decades each President of the United States, his delegation in the Secretary of State's office and elsewhere, and Congress, have been constantly at work deciding what is the right level of emissions, what is the right way to tackle global warming, should we have

multi-lateral treaties to get at this issue, should our energy policy change? After all, again, I represent companies, coal companies, who do nothing but engage in lawful activities, and there is no allegation otherwise in this case. And those activities are at the center of this nation's energy policy under the commerce clause, as the Judge knows. That is what Congress does. It sets forth our country's energy policy. So when you have the combination of a global issue and global action by our nation's political branches, you have, inescapably, I would say, a political question.

As I have suggested, and the briefing spells this out, therefore, the Supreme Court isn't interested so much in the labels of causes of action, and there are very important and consistent Supreme Court cases where if all the Court did was said, this is a trespass claim, this case seeks only damages, and therefore acts, we have a very different doctrine. The Court doesn't do that. No Court does that. The Courts look beyond the labels, and they ask, as I said, what has to really be resolved to get from a complaint to a verdict? And here, as I have said, that path is fraught with nothing but political questions. And that, I think, Judge, is why no Court yet has seen fit to adjudicate claims like this. There just hasn't been a Court put in the position that the Comer complaint is putting Your Honor in.

Judge, that is what I had to say on the issues. Of

course, I am thrilled to answer your questions.

THE COURT: If you know, recently the United States Supreme Court addressed a somewhat similar question in *Massachusetts versus Environmental Protection Agency,* and I probably am oversimplifying the decision, which was, the Environmental Protection Agency must act. Has the Environmental Protection Agency taken any action as a result of the mandate from the Supreme Court?

MR. WINKELMAN: That is something I should know, Judge. I do not. I suspect there are people in this courtroom who do. What we do know is that the Supreme Court has said that the EPA has to now take steps, but I am afraid I can't answer your question.

THE COURT: Thank you, Mr. Winkelman.

MR. WINKELMAN: Would you like me to address Mass. v. EPA, or is that sufficient for your purposes?

THE COURT: That is sufficient for my purposes.

MR. WINKELMAN: Thank you, Judge.

THE COURT: Thank you. Mr. Maples?

MR. MAPLES: I will apologize at the outset. I will be reading a great deal of my presentation. The constraints of time do not allow me that cherished luxury of rambling, so my apologies for this particular format.

In responding to a couple of the points made by opposing counsel, regarding the three tests under *Lujan,* it seems to me

that we really are focused on the second test, that number three, redressability, is taken care of, and the jurisprudence is very clear on this by the fact that this is a case requesting monetary damages, not injunctive relief or anything that would invade the Article I and II branches' authority or the fields they have occupied.

The traceability requirement, number two, I think it is fairly obvious in defendants' briefing in this case that the absence of a serious foreseeability analysis in that briefing indicates that really what they are trying to do is confuse the traceability issue by failing to address it as a foreseeability issue, and, in fact, what they are talking about is some sort of confusion in arriving at apportionment of liability and damages. I think that is what they are talking about, in fact, and I do not believe that that is an appropriate matter for inquiry on a 12(b)(6) motion such as this, even though we are dealing with an in depth look at political question and standing.

With regard to foreseeability, it really does not matter how many links there are in the chain. What we are really talking about are issues that arose, for instance, in a couple of Mississippi cases that are important proximate cause cases, *Ogburn versus City of Wiggins,* as well as *Owens Corning versus R. J. Reynolds.* Is there an intervening cause, or in fact are we trying to mask what should be a subrogation claim as

something else because contractual subrogation is not available? We don't have those problems here, and we do know how much CO_2 these defendants have put into the atmosphere, both by virtue of their operations in the United States and their worldwide operations. We can get there. As the Court recognized in *Massachusetts versus EPA*, we don't have to have every defendant before the Court in order to satisfy the redressability requirement.

With that said, I also would like to point the Court, with regard to opposing counsel's statements on political question, to page 12 of the complaint, the two footnotes, where we make it clear that the Article I and II branches have done nothing with regard to addressing the problems that ultimately led to the damages complained of in this case. They have done nothing to redress the problems, and I will not stand here and read that language to the Court verbatim, but we strongly disagree with counsel that there is anything in our complaint that would say otherwise.

We are dealing with a hearing here today that uses Rule 12(b)(6) as a vehicle for analysis of the political question and standing issues. It has to be done by the Court looking at the face of the complaint and looking only within the four corners of the complaint. That is clear. The Court certainly should apply the Baker decision and look at the six criteria, or the three criteria in *Lujan*, but the analysis, according to

the case law, the Court is required to conduct a careful and delicate analysis when applying Baker criteria.

This case is about a nuisance claim based upon federal common law, as well as the nuisance law of the State of Mississippi. It is based on a negligence claim, and we have an unjust enrichment count. That is what it is. It is a lawsuit, lawsuits just like we see all the time, just like the Court has seen on many occasions. The judge and jury will decide foreseeability, duty, breach of duty, reasonableness of conduct, and redressability, or, in the language used by the Mississippi Supreme Court for the Mississippi causes of action, duty and law, which is more often than not decided by the Court, and cause in fact, which is decided primarily by the trier of fact.

In the Fifth Circuit case of *Cox versus City of Dallas*, with regard to nuisance claims, the Fifth Circuit has recognized that "strict liability is often applied in nuisance cases. The reasonableness of the injury and risk imposed on the property owner who is complaining of damage is the more important inquiry in a nuisance case, not necessarily just the reasonableness of conduct. An activity can be perfectly legal and still be a nuisance if the injury to one's fellow property owner is unreasonable under the circumstances." Unjust enrichment, as we all know, requires certain, the application of certain equitable principles, which this Court certainly has

the authority to do.

This is a case that asks the Court to perform its traditional Article III role to identify the controversy between the parties, apply federal law and Mississippi law, and apply an appropriate remedy. Here is what this case is not and what it does not do: It is not a case that requires the determination of what would be an appropriate level of CO_2 emissions. It is a case that requires the Court and the jury to address what constitutes unreasonable conduct pursuant to Mississippi law and Federal Common Law on the part of a defendant or defendants. It is not a case that asks this Court to make policy. It does not request injunctive relief. It does not affect Presidential power. It has no precedential effect outside of this state except perhaps decisions concerning Federal Common Law.

In prosecuting this case, it does not matter and should be of no concern in the prosecution of this case if this case were to cause the filing of a thousand similar cases in a thousand different courtrooms, nor is it of any concern in the prosecution of this case by the parties or the Court if as a result of this case there is a change in corporate behavior. Oftentimes Court decisions and results effect a change in behavior in society. It does not affect, limit, or invade Congressional power. It does not require the Court to make any impossible predeterminations. It is not a case against a

foreign sovereignty, such as the Nazi reparations case that has been cited by the defendants. It is not a case involving the Civil War or 600 years of reparations where Congress and the White House long ago completely occupied the field.

These defendants, often in concert, have fought regulation and sought a system of voluntary self-regulation. In the process they have discredited honest, sincere science and honest, sincere scientists and waged a fierce disinformation campaign. They have succeeded in avoiding regulation and have gambled away the opportunity to seek preemption. Now they want other people to pay that gambling debt. Congress and the White House have done nothing to occupy this field. Using the defendants' reasoning we can infer that Congress has refused to preempt this case and refused to enjoin this and the other Courts from hearing a case such as this.

In the MTBE case that was cited, a United States District Court case out of the Second Circuit that so clearly delineates the difference between a case such as Comer and the *Connecticut versus AEP* case. The Court said, "The defendants have blurred the line between a case for compensation and the national policy interest and the composition of the nation's fuel supply." We believe that that same attempt is being made here in the Comer case, to blur that line.

And, in fact, regulation, were there some regulation in place, does not always preempt tort litigation. There are many

examples of that, and that is covered in the *Spreitzma versus Mercury Marine* case, and we can point to such federal regulatory laws as the Vaccine Act as other examples.

12(b)(6) does not allow the Court to determine the weight of the evidence today, a determination of fact reserved for the jury, Rule 56 determinations, matters related to class certification, or factual issues related to reasonableness of conduct, foreseeability, or cause in fact. It also does not allow the Court to determine the appropriate measure of damages or the appropriate damage model.

On April 2, 2007, the United States Supreme Court handed down the case of *Massachusetts versus EPA*, and here is what we learned: The EPA did not contest causation; Massachusetts has standing to represent its citizens; the size of the problem does not minimize that standing; and the numerosity of injured parties or potential injured parties does not defeat standing or create a political question; in order for standing to exist, the particularization doctrine does not require proof of the precise degree of anticipated damages, only reasonable certainty that damage will occur; all responsible parties do not have to be before the Court, nor is it required that the Court address all of the plaintiffs' damages in order to meet the recompensability requirement. I will further read from the Massachusetts decision. One reason the Court found that jurisdiction did in fact exist was, quote-unquote, the unusual

importance of the underlying issue persuaded us to grant the writ.

The MTBE case states that cases are nonjusticiable only to the extent that they are beyond the competence and proper role of the courts. In *Gordon versus Texas* the Court recognized that monetary compensation is the manifest object of the savings clause. The Courts almost never find Baker-based nonjusticiability in monetary compensation cases.

I note something very interesting from the *Baker versus Carr* case on page 15. The moving parties, parties moving in favor of nonjusticiability, had quoted extensively from a prior opinion by Justice Frankfurter, and in *Baker versus Carr* they note this: "Commentators have suggested that the following statement in Mr. Justice Frankfurter's opinion might imply a view that appellants there had no standing." And they quote Justice Frankfurter. "This is not an action to recover for damage because of the discriminatory exclusion of a plaintiff from rights enjoyed by other citizens. The basis for this suit is not a private wrong, but a wrong suffered by Illinois as a polity." In making the distinction that that was not a case for monetary damages, we believe what Justice Frankfurter was saying is that had it been, then in fact it would be -- it clearly would be a case over which an Article III Court had jurisdiction.

This Court has the ability to identify the parties at

interest and to identify the appropriate laws, evidence, and remedies. There may come a time when this Court decides that this case cannot go forward, but this is not the time or vehicle for doing so. The plaintiffs are entitled to move forward, conduct discovery, and explore the factual issues related to the elements of their causes of action. They are entitled to move toward and learn about what the defendants actually knew, compared to what they publicly said. They are entitled to learn about the defendants' joint enterprises, efforts, and how it may create joint and several liability under the Mississippi tort statutes. In short, in the absence of any specific and clear showing that meets one or more of the Baker criteria, they are entitled to the full protection of the savings clause, the Fifth and the Seventh Amendments.

In closing I would like to direct this Court and this courtroom's attention to footnote 18 of *Massachusetts versus EPA*. "We note with sadness and with graditude and hope the U.S. Supreme Court's reference to Hurricane Katrina, sadness because it represents a recognition of the magnitude of what happened here on the Mississippi Coast, gratitude because it represents a recognition of the significance of what happened here on the Mississippi Coast, and hope that at least five of the nine justices would approve of and respect what the plaintiffs are trying to accomplish here in this courtroom on the Mississippi Coast. Thank you, Your Honor.

THE COURT: Mr. Maples, if I could address a couple of questions before we move on to Mr. Winkelman's rebuttal. I will ask you the same question I asked Mr. Winkelman. Are you aware of what steps the Environmental Protection Agency has taken as a result of the mandate of the Supreme Court?

MR. MAPLES: The EPA?

THE COURT: Yes.

MR. MAPLES: I am not. I have actually considered that issue, but we don't have any information as of yet.

THE COURT: But we agree that they were mandated to at least take a look at the effects of greenhouse gases on the environment and to take some action and in fact regulate them?

MR. MAPLES: Only with regard to automobile emissions.

THE COURT: Now, I think -- I would like to try to understand a little better the plaintiffs' causes of action. I think you have characterized them as nuisance and negligence, and I think you also mentioned unjust enrichment. I will concentrate on the nuisance and negligence aspect of it so we can eliminate some causes of action. There is no cause of action here that is based upon a federal statute or federal regulation?

MR. MAPLES: No.

THE COURT: Likewise, there is no cause of action here that is based upon a Mississippi statute or a Mississippi

regulation?

MR. MAPLES: No, Your Honor.

THE COURT: There is no cause of action, quote-unquote, global warming style cause of action based on any decision by the Mississippi Supreme Court?

MR. MAPLES: This has nothing to do with global issues, Your Honor.

THE COURT: You made the statement earlier, and it caught my attention because you said that what this case is about is that a Court, I think you said a Court, or the judge and the jury must determine what constitutes unreasonable conduct. What measuring rod would the Court and the jury be armed with? What would an instruction look like, an instruction to the jury that they are to consider the conduct of the defendants under XXX standard? How would they do that?

MR. MAPLES: One thing that comes to mind is what is often referred to in jurisprudence as the reasonable man standard. What would a reasonable man do under the circumstances given the level of knowledge that that person had concerning the potential risk, the foreseeability of that risk, and the impact that that risk might have on fellow citizens?

THE COURT: Wouldn't you agree that any emission or any contribution to greenhouse gases, that cannot be a good thing, and, consequently, there must be some standard by which a jury could conclude that at some point so much has been

contributed to the -- so much greenhouse gas has been contributed to the atmosphere that it reaches a point of negligence or unreasonable conduct. Where is that -- where is that point? When do we reach that point? How do we know, for example, when a particular coal mining or coal producing defendant has crossed the line between acceptable legal conduct and negligent or unreasonable conduct?

MR. MAPLES: As an example of crossing the line, I think we have to look at the conduct of the parties, their actions in concert, whether or not they were making a good faith effort to learn the effects of their products, to promote science, or were they in fact doing something else and visiting a giant fraud on the public at large. They cannot say that the public at large are contributors to this cause if it was their conduct that caused a confusion in the eyes of the public at large as far as what the scientific truth was. Not only is that evidence against these corporate defendants and their industry organizations that engaged in these kinds of activities, but it is also evidence in favor of the plaintiffs' position that the average person didn't have the foreseeability to be a joint tortfeasor or a contributor and didn't have any good options.

THE COURT: Are you telling me that ultimately the standard that the jury would apply would be what would a reasonable emitter of greenhouse gases do?

MR. MAPLES: Based upon the law and the evidence, and that was the reason --

THE COURT: Who would set that standard of what a reasonable emitter is permitted to --

MR. MAPLES: It doesn't have to be a scientific standard. This Court doesn't have to make a predetermination about what would be a good policy or bad policy decision concerning levels of emissions into the atmosphere. The defendants would have you, Your Honor, think that, and therefore say that it is nonjusticiable. That is not the case. If these defendants knew full well what they were doing, if they knew that this problem was getting worse and worse and worse, if they hid the truth, if they were deceitful about the science, then I think this Court can formulate jury instructions that submit that question to the jury based upon the evidence, but we have to go through the whole discovery process to see what all of the evidence is.

THE COURT: I am also -- I suppose that the plaintiffs do not take the position that all of us here are co-defendants or producers ourselves every morning when we get into our automobiles of emissions that ultimately contribute to the gases?

MR. MAPLES: No, Your Honor. Part of the consideration is who was in a position to prevent this harm, who was not just best in position but who was in a position at

all? Who was in a position to know what the truth is regarding the foreseeability issue? And I don't think most people, in this country anyway, in this state, have until perhaps just recently recognized what a problem, what kind of problem exists, and I believe they were deliberately confused or misled, and I think that will be a very significant part of the evidence.

We also have a distribution system in this country that doesn't allow us any alternatives. I have tried to find an alternative personally. I can't do it. I can't buy a plug-in hybrid vehicle. I can't buy one -- I have tried to get in touch with people in California that sell these things to owners of fleets of vehicles. I can't do it.

THE COURT: That would probably be well beyond the means of the average person anyway.

MR. MAPLES: It would indeed. Where are the bio-fuel distribution points? I can't buy bio-diesel. You would have to ride a thousand miles to buy a tank of bio-diesel.

THE COURT: Well, and I don't -- I am glad that you concede that we are not all co-defendants, but do you concede that we are all at fault?

MR. MAPLES: No, sir.

THE COURT: You do not?

MR. MAPLES: I do not. I do not think there is fault on the part of the average user.

THE COURT: Well, is there fault elsewhere? And I don't refer to -- is there fault perhaps not just by the producers here in our nation but producers elsewhere in other countries?

MR. MAPLES: Not fault under our law in Mississippi or Federal Common Law.

THE COURT: Well, I am not sure. How would you administer the Mississippi apportionment of fault statute in a situation like this? Assuming that the defendants raised apportionment of fault and I had to instruct the jury on apportionment of fault, how would I instruct the jury?

MR. MAPLES: There are two options here, one to find that other manmade contributions to the CO_2 problem did not have any duty under the laws of the State of Mississippi or Federal Common Law. The other option would be for the Court to find out that they were in fact contributors in fact and that these defendants that are before the Court and over which we do have in personam jurisdiction should not be held accountable for that part of the damages. It is a distinguishment between liability and apportionment of damages, apportionment of fault based on liability and damages.

But there is also another issue that I alluded to in my presentation, and that is the Mississippi tort liability statutes have a provision when there is a concerted -- when there is concerted activity, those participants in that

concerted activity can be held jointly and severally liable.

I make one other point as well. The United States contributes to 25 percent of the global CO_2 emissions, activities in the United States, but that doesn't mean that that is all that these defendants are responsible for. That is just activities of the United States. Some of these defendants are some of the biggest corporations in the world, and their contribution is much more than just their portion of what happens in the United States. But ultimately, if the Court decided that these defendants in toto contribute X percentage to the worldwide, and they should only be held liable for that part of the damages, *Massachusetts versus EPA* makes it very clear we don't have to have all the responsible parties before the Court, and the Court, in order to satisfy redressability, is not required to be able to compensate plaintiffs for all of their injuries.

My young learned colleague has suggested that we look to Learned Hand to analyze the risk, the extent of the harm, and the cost of change. The jury's job is not to set the standard but to evaluate the conduct under specific facts and circumstances.

THE COURT: Thank you, Mr. Maples.

MR. MAPLES: Thank you, Your Honor.

THE COURT: Mr. Winkelman?

MR. WINKELMAN: Briefly, Judge. Thank you. My

distinguished colleague began by saying that we have misunderstood the causation piece of standing, and that really it is about, and I quote, "foreseeability and about intervening events," and I would suggest respectfully that there is not a single Supreme Court case that suggests that. Every time the Supreme Court has spoken to traceability and whether the link is fairly traceable. It talks about exactly, Judge, what we have been talking about. It talks about the links that are necessary to get from this emission to 123 Jackson Street, Mississippi. That is precisely what we are talking about. That concept is familiar in tort law, as Your Honor is aware, and it is at the center of constitutional standing.

Number two, my colleague suggests that they haven't really in their complaint suggested that there has been action by our political branches. And if you don't mind, Judge, if I can briefly approach the bench?

THE COURT: Sure. These are portions of the complaint?

MR. WINKELMAN: Exactly, Judge. Judge, you are exactly right. I mentioned earlier on the footnotes in the complaint, and that is what I have handed you, and as you will see, what the plaintiffs have told you in their third amended complaint is that the Article I and the Article II components of our Federal Government, that is, Congress and the President, have refused to act, but then later you will see they say, "and

have taken the wrong actions." And that is not the only time, Judge, they say that. On that very same page in that complaint they criticize the dearth of meaningful political action.

So I would say, Judge, as I said earlier, we have the unusual case where the plaintiffs themselves concede, because they have to, they are honest people, concede that our political branches have been active, not just debating, by the way, not just researching, active in deciding political questions about global warming.

The next thing my able colleague says is that regulation doesn't always mean political question. And they are exactly right about that. The curious thing, though, that they say is look at the MTBE case. The reason I say that is curious is, what did Judge Scheindlin do in the Southern District of New York in that case? She said, and now I paraphrase, I have to distinguish MBTE(sic) from global warming. Why? And I quote, Judge, "because the claims regarding global warming were unique in the context of pollution as public nuisance cases, as they 'touched on so many areas of national and international policy.'" Judge Scheindlin says exactly what our clients have said about why this case, perhaps unlike many, like MTBE, for instance, is bound up in political questions.

Plaintiffs make much of *Massachusetts v. EPA,* and we talked about that briefly, and I only want to make sure we understand what that case was. Of course, it was not a tort

case. It was a case of statutory construction. You are right in your characterization, Judge, of it. And what the Court found is that Congress had already granted the State of Massachusetts a procedural right. It had already decided that that state, among many others, can ask for EPA activity, and what the majority thought it was doing, whether we agree or not, was simply enforcing bad acts and deciding that states get special solicitude and don't need to honor the usual standards of traceability and redressability. So if there is anything we know, Judge, about *Mass. v. EPA*, is that not a single justice would think that *Mass. v. EPA* standing analysis would find standing here. We know the four member dissent wouldn't, and the majority itself, by applying special solicitude and relaxed standards, is functionally telling us the same thing. So I walked in, Judge, thinking actually that the most analogous case, the most obvious reason not to find standing here, in fact, is *Mass. v. EPA*.

Finally, Judge, and I will stop, my worthy adversary said, what courts don't do in the political question world is find political questions when there is a claim for damages. Judge, we cited you cases precisely the opposite, and I will end by simply discussing a single case, because it goes all the way back to 1849. It is called *Luther v. Borden*, and it was as simple and practical as this case. It was a trespass case. It was only about damages. Mr. Luther said that Mr. Borden broke

into and entered his house. So if all we did is look at those labels, what the Supreme Court would have found in 1849 was no political question. It found the opposite because it turned out that the breakers and enterers said they were authorized to do so because they were the lawful agents of the properly constituted government of Rhode Island at a time of martial law, a fairly important detail. And what the Supreme Court decided was that to resolve this seemingly simple trespass case about only damages, it would have to decide issues that only the Congress can decide. So there is plenty of precedent, Your Honor, for my earlier point that, unfortunately, semantic cataloguing, the quote from the Supreme Court, doesn't work. It doesn't much matter what the labels are in the complaint. What matters is, what are the issues that have to be adjudicated. Thank you, Judge.

THE COURT: Thank you, Mr. Winkelman. I will take a short recess, and when I return, I will tell you where we are going to go. Thank you.

(RECESS TAKEN AT 10:06 A.M. UNTIL 10:32 A.M.)

THE COURT: Thank you. Please be seated. One of the questions that I pondered with some of the staff attorneys during the recess was just why weren't the plaintiffs able to find a nondiverse party. Having failed in that responsibility, the Court will here give it its best shot.

I have struggled because it is very easy to be inclined to

want to, quote-unquote, do the right thing at all times. And you have got to weigh that, balance that, with the authority that you have under Article III and the responsibility you have to follow the law, or in this case the absence of law.

While the plaintiffs argue that this is not a case about global warming, it really is. It is a case wherein the plaintiffs have rung a bell that should not come as a surprise to many of us, anyone who reads the newspaper or watches the television, anyone who is aware of the science and has taken any time at all to do some independent research.

Let me point out that it is very apparent, Mr. Maples, while you make your arguments that you and in all likelihood those that sit with you on that side of the courtroom are passionate about this issue, and you have a right to be passionate about it. I think it would be unwise for any of us as citizens of this planet to ignore the science and to ignore the signs, if you will, of what we are doing to our planet and what we are doing to our environment, what we are doing to our atmosphere, and what legacy we will hand down to our children and grandchildren. As an individual, I am concerned about that, but as a judge of this court, I don't have the luxury of being an individual. I have the responsibility to administer the law.

In this case it seems apparent to the Court, based upon the arguments of counsel and based upon the very

well-articulated arguments that you have made in your brief, that this Court does not have standing to adjudicate these issues. These are not injuries which are fairly attributable to these individual defendants. And while plaintiffs have argued that we are not -- I am gratified to know I am not a co-defendant, but I am a responsible person, as all of us are responsible for the emission of CO_2 and ultimately greenhouse gases which cause global warming. We are all responsible for that. But I do not think that under our system of jurisprudence that is attributable or traceable to these individual defendants but is instead or are instead injuries which are attributable to a larger group that are not before this Court, not only within this nation but outside of our jurisdictional boundaries as well. In the opinion of the Court, these plaintiffs do not have standing and this Court does not have justiciable issues before it.

Alternatively, and I think I am going to speak briefly about the political question issue because it is somewhat intertwined with the standing question, that question of whether or not this is a political question. I have done some independent research that you may not find in the law books that tends to underscore, if you will, the realization that the problem is one in which this Court is simply ill-equipped or unequipped with the power that it has to address these issues. For example, I am sure that many of you here know that

effective as of January of 2007 that the State of California has enacted its own Global Warming Solutions Act of 2006. This particular act in California requires the State Air Resources Board there to adopt regulations that require reporting and verification of statewide greenhouse gas emissions and to monitor and to enforce compliance with these programs. The act also requires the board to determine what the statewide greenhouse gas emissions levels were in 1990, and to establish emissions limits that are equivalent to the 1990 levels by the year 2020. These are, of course, efforts taken on by the California legislature. Connecticut, Washington, Maine, Vermont, New York, Pennsylvania, Rhode Island, Maryland, New Jersey, Oregon, and Massachusetts have all enacted plans that are similar to the California act. I cite as an example, the California and Maine acts have enacted what they call the Climate Change Action Plan that establishes the goal of reducing emissions to the 1990 levels by the year 2020. Maryland has set limits on the amount of greenhouse gases that can be emitted from facilities utilizing coal burning or fired heat exchangers. New Jersey has required enactment of regulations requiring monitoring and reporting of greenhouse gas emissions. Georgia, Alaska, Colorado, Idaho, South Carolina, and Florida have established advisory committees that study the effect of global warming and determine measures that can be taken to mitigate the problem. Nebraska has established

a carbon sequestration advisory committee to conduct research concerning agricultural advances that would reduce greenhouse emissions. The state of Iowa has enacted statutes that require the Department of Natural Resources to establish voluntary greenhouse gas inventory and registry, an energy independence plan that would decrease reliance on foreign oil, and a climate change advisory council. New Hampshire has developed a voluntary greenhouse gas emissions reduction registry as well. And Virginia has adopted a Commonwealth Energy Policy that will promote the generation of electricity through technologies that do not contribute to greenhouse gases and global warming. The legislatures in Alabama, Illinois, Kentucky, Georgia, Oklahoma, Wyoming, and West Virginia have all adopted statutes providing the development of new regulatory programs intended to reduce greenhouse gases and their emissions are premature absent some Senate ratification of the Kyoto Protocol. Of course, these states fear that piecemeal uncoordinated regulations may be inconsistent with subsequent determinations that are made by our Congress, and the premature enactment of such regulations would hurt the economy. Georgia and Oklahoma have, of course, developed voluntary reduction programs, and Illinois has enacted the Clean Coal FutureGen Project for Illinois Act which would develop carbon storage and capture plans for fossil fuel energy and hydrogen-generating units. The State of Illinois has a goal of at least five percent of the state's energy

production -- use derived from renewable sources or forms of energy by 2010, and at least 15 percent by 2020.

I bring this to your attention, and I think many of you may already know some of these things, because I think, again, that underscores the arena in which this debate needs to be discussed. It is a legitimate debate. It is an important debate, but it is a debate which simply has no place in the court, until such time as Congress enacts legislation which sets appropriate standards by which this Court can measure conduct, whether it be reasonable or unreasonable, and, more important, develops standards by which a group of people, we call them juries, can adjudicate facts and apply the law, these standards, and judge whether conduct crosses the line between reasonable and legal conduct and unreasonable or tortious conduct. Under the circumstances, I think that the plaintiffs are asking the Court to develop those standards, and it is something that this Court simply is not empowered to do.

This is not a case such as *Massachusetts versus EPA* where the State of Massachusetts simply wanted to require the Environmental Protection Agency to, in essence, do its job. This is not a case in which these defendants, for example, have done some damage, some attributable damage to the wetlands or to the floor of the wetlands, which, in essence, has made damage as a result of hurricanes more likely. Instead, this is a case in which the plaintiffs directly ask this Court to

attribute fault to these defendants under standards that as of yet do not exist.

It is clear from the complaint and clear from the arguments here today that what you are asking this Court to do is what *Baker versus Carr* told me not to do, and that is to balance economic, environmental, foreign policy, and national security interest and make an initial policy determination of a kind which is clearly nonjudicial. Adjudication of the plaintiffs' claims in this case would necessitate the formulation of standards dictating, for example, the amount of greenhouse gas emissions that would be excessive and the scientific and policy reasons behind those standards. These policy decisions are best left to the executive and to the legislative branches of the government, who are not only in the best position to make those decisions but are constitutionally empowered to do so.

Finally, one practical note, and it became very apparent, Mr. Maples, during your argument, that the preparation and the discovery involved in a case of this magnitude will take a long time and will cost both sides millions of dollars. It seems to me that it would be a much better course of action to take. And, of course, I am convinced that I am right, but I could be wrong, but if I am wrong, I can be corrected, and the Court of Appeals will have no hesitation to correct me and send this case back, at which time we will conduct the discovery

necessary to prepare it for trial. If, on the other hand, I were to take the other course, which I think would be incorrect, and that is to permit the case to go forward and rule against the defendants on the standing issue, I would be inviting the prospect or the proposition that after spending millions of dollars and countless hours, man-hours, in preparation of the case, that it would be reviewed by an appellate court that would conclude that it was not an issue that was justiciable by the Court, and ultimately all our work would be in vain.

The defendant's motion to dismiss is granted. In addition to that, the Court is sua sponte dismissing all of the remaining defendants. This will place this case in a procedural posture in which all of the parties, plaintiffs and defendants, can have this matter reviewed in the event that I am in error. I will enter that order today. Anything else on behalf of the movants or the defendants? Any questions?

MR. WINKELMAN: No, Your Honor. Thank you.

THE COURT: Mr. Maples, anything else on behalf of the plaintiffs? I guess, in essence, what I am saying, if I have no standing as to these defendants, there is no standing as to any of the defendants.

MR. MAPLES: Your Honor, may I make one request?

THE COURT: Yes.

MR. MAPLES: Would you make clear which version of

the complaint is at issue?

THE COURT: The fourth amended complaint. The fourth amended complaint is what is on file.

UNKNOWN SPEAKER FROM AUDIENCE: The fourth amended complaint is on file or the third amended complaint is on file?

THE COURT: I'm sorry. The third amended complaint is on file. There is leave to file a fourth amended complaint, which, of course, is moot at this point. The third amended complaint is the one that is before this Court.

MR. MAPLES: And there is no ruling on the fourth amended complaint?

THE COURT: In the event that I am in error and there is standing, then I will consider whether or not an additional amended complaint will be allowed.

MR. MAPLES: Thank you, Your Honor.

THE COURT: I'm sorry. I took one step. Of course, all additional motions are rendered moot. I will enter an order accordingly. If there is nothing else, we are adjourned.

(HEARING CONCLUDED.)

CERTIFICATE OF COURT REPORTER

I, Teri B. Norton, RMR, FCRR, Official Court Reporter for the United States District Court for the Southern District of Mississippi, appointed pursuant to the provisions of Title 28, United States Code, Section 753, do hereby certify that the foregoing is a correct transcript of the proceedings reported by me using the stenotype reporting method in conjunction with computer-aided transcription, and that same is a true and correct transcript to the best of my ability and understanding.

I further certify that the transcript fees and format comply with those prescribed by the Court and the Judicial Conference of the United States.

Teri B. Norton

TERI B. NORTON, RMR, FCRR
OFFICIAL COURT REPORTER

EXHIBIT C

IN THE UNITED STATES DISTRICT COURT
FOR THE SOUTHERN DISTRICT OF MISSISSIPPI
SOUTHERN DIVISION

NED COMER, ET AL.	§	**PLAINTIFFS**
	§	
v.	§	**Civil Action No. 1:05-CV-436-LG-RHW**
	§	
MURPHY OIL USA, INC., ET AL.	§	**DEFENDANTS**

<u>ORDER GRANTING DEFENDANTS' MOTION TO DISMISS</u>

THIS CAUSE CAME BEFORE THE COURT for hearing of the Motion to Dismiss [146] filed on June 30, 2006, by Defendants, Alliance Resource Partners, L.P., Alpha Natural Resources, Inc., Arch Coal, Inc., CONSOL Energy Inc., Foundation Coal Holdings, Inc., International Coal Group, Inc., Massey Energy Company, Natural Resource Partners L.P., Peabody Energy Corporation, and Westmoreland Coal Company, and joined by Defendants, Allegheny Energy Corp., Entergy Corp., and Reliant Energy Corp. A hearing was conducted on August 30, 2007, at which counsel for Plaintiffs and Defendants appeared. For the reasons stated into the record at hearing, the Court finds that Plaintiffs do not have standing to assert claims against Defendants and that Plaintiffs' claims are non-justiciable pursuant to the political question doctrine. Defendants' Motion to Dismiss is therefore granted. Furthermore, due to the lack of standing, the Court finds that Plaintiffs' claims against all defendants should be dismissed *sua sponte*.

IT IS THEREFORE ORDERED AND ADJUDGED that the Motion to Dismiss [146] filed by Defendants, Alliance Resource Partners, L.P., Alpha Natural Resources, Inc., Arch Coal, Inc., CONSOL Energy Inc., Foundation Coal Holdings, Inc., International Coal Group, Inc., Massey Energy Company, Natural Resource Partners L.P., Peabody Energy Corporation, and

Westmoreland Coal Company, and joined by Defendants, Allegheny Energy Corp., Entergy Corp., and Reliant Energy Corp., is **GRANTED**. Plaintiffs' claims against these defendants are hereby **DISMISSED WITH PREJUDICE**.

IT IS FURTHER ORDERED AND ADJUDGED that Plaintiffs' claims against all other defendants are *sua sponte* **DISMISSED WITH PREJUDICE** for lack of standing.

IT IS FURTHER ORDERED AND ADJUDGED that all remaining pending motions are hereby rendered **MOOT**.

SO ORDERED AND ADJUDGED this the 30th day of August, 2007.

s/ Louis Guirola, Jr.
LOUIS GUIROLA, JR.
UNITED STATES DISTRICT JUDGE

EXHIBIT D

US Army Corps
of Engineers
Alaska District

Alaska Village Erosion Technical Assistance Program

An Examination of Erosion Issues in the Communities of Bethel, Dillingham, Kaktovik, Kivilina, Newtok, Shishmaref, and Unalakleet.

April 2006

Executive Summary

This report was prepared as a response to legislation that directed the U.S. Army Corps of Engineers (Corps) to investigate issues surrounding erosion at several Alaska Native villages. As part of this effort, the Corps examined erosion rates and control, potential relocation, and impacts to Alaska Native culture and tradition. The Alaska Village Erosion Technical Assistance (AVETA) program is a compilation of efforts in numerous communities funded through the Tribal Partnership Program and subsequent legislation.

Specifically, this report documents the responses to questions raised in the Consolidated Appropriations Resolution, 2003 PL 108-7, Division D - Energy and Water Development Appropriations, 2003, Conference Report (H.R. 108-10, page 807) and Senate Report (S.R. 107-220, page 23) with regards to the communities of Bethel, Dillingham, Kaktovik, Kivalina, Newtok, Shishmaref, and Unalakleet.

The questions asked were: what are the costs of ongoing erosion, what would it cost to relocate a community, and how much time do these communities have left before they are lost to erosion. The following table summarizes the answers to these questions.

Community	Costs of Future Erosion Protection	Cost to Relocate	How Long Does The Community Have*
Bethel	$ 5,000,000	N/A	> 100 years
Dillingham	10,000,000	N/A	> 100 years
Kaktovik	40,000,000	$ 20 – 40 Million	> 100 years
Kivalina	15,000,000	$ 80 – 120 Million	10 – 15 years
Newtok	90,000,000	$ 80 – 130 Million	10 – 15 years
Shishmaref	16,000,000	$100 – 200 Million	10 – 15 years
Unalakleet	30,000,000	N/A	> 100 years

*These numbers assume no future erosion protection, including that listed here, is not implemented

This report documents the wide variety of efforts the Corps is undertaking through Tribal Partnership funding to address ongoing erosion problems in Alaska. Many issues related to erosion protection and community relocation are also discussed in this report. Most importantly, each village has a summary of findings that explores solutions for these most critical villages. This report also describes other Corps efforts such as the Baseline Erosion Assessment, which documents the Corps strategy to address erosion in Alaska both now and in the future.

This technical report has been prepared by the Alaska District, U.S. Army Corps of Engineers in coordination with and with the assistance of multiple agencies, villages, and stakeholders.

1.0 INTRODUCTION

This report was prepared as a response to legislation that directed the U.S. Army Corps of Engineers (Corps) to investigate issues surrounding erosion at several Alaska Native villages. As part of this effort, the Corps examined erosion rates and control, potential relocation, and impacts to Alaska Native culture and tradition. The Alaska Village Erosion Technical Assistance (AVETA) program is a compilation of efforts in numerous communities funded through the Tribal Partnership Program and subsequent legislation.

2.0 STUDY AUTHORITY

The authority for this study is the Consolidated Appropriations Resolution, 2003 PL 108-7, Division D - Energy and Water Development Appropriations, 2003, Conference Report (H.R. 108-10, page 807) and Senate Report (S.R. 107-220, page 23), which reads as follows:

> *"The Committee acknowledges the serious impacts of coastal erosion due to continued climate change and other factors in the following communities in Alaska: Bethel, Dillingham, Shishmaref, Kakatovik, Kivalina, Unalakleet, and Newtok. The Committee directs the Corps to perform an analysis of the costs associated with continued erosion of these communities, potential costs associated with moving the affected communities to new locations (including collocation with existing communities), and to identify the expected time line for a complete failure of the useable land associated with each community. An additional $2,000,000 above the President's request has been provided for this work, of which $1,000,000 is for Shishmaref, AK. Due to rapid erosion occurring at Shishmaref, AK, the Committee directs the Corps to expedite all necessary environmental studies to document the impacts of this severe and continuing erosion."*

3.0 STUDY PURPOSE

Each village had its own study effort, and this report summarizes and compiles the findings for the entire effort. The primary purpose of each study was to respond to the three questions asked by Congress. These questions are stated in Section 2.0 but are repeated here for clarity.

1. What are the costs associated with continued erosion of these communities?
2. What are potential costs associated with moving the affected communities to new locations or an existing community?
3. What is the expected time line for complete failure of the usable land associated with each community?

A secondary purpose of the studies was to provide technical assistance or studies that the particular community would find beneficial. The technical assistance took the form of relocation planning, cultural resource inventories, and investigation of interim erosion protection features.

4.0 STUDY METHODOLOGY

As mentioned in the congressional language, certain issues such as costs of erosion and relocation are subjects of keen interest to many. To answer the questions presented by Congress, certain assumptions were made to ensure consistency of analysis between the

various villages. The following is a description of issues we identified, what assumptions were made, and how we analyzed each question

4.1. Relocation Planning Issues and Assumptions

The following is a listing and discussion of a few key issues, how they were resolved through assumptions for this analysis, and what may need to happen to resolve these issues in a more complete manner.

Who selects the new site?
The issue of who does the site selection depends upon jurisdiction and ownership. Whereas the community plays the major role in the selection of an appropriate site, they may not have jurisdiction to choose a site that is in public ownership or has been encumbered through some prior agreement. We have not addressed this issue is this analysis; however, it is a critical item that will need to be addressed as part of relocation planning. The assumption for this analysis is that an adequate site could be identified and acquired through a reasonable process in a reasonable amount of time. It should be noted that the Community of Newtok already has identified and acquired a new location for their community.

What are the criteria used for selecting a new site?
Though specific sites, with the exception of Newtok, have not been identified, certain assumptions have been made regarding criteria for a new location. Most importantly, a new location would not be in a flood or erosion hazard area. It would have enough developable space available to allow room for the existing community to settle plus some room for spreading out or expansion. A new site would also need to be accessible to a water supply, subsistence, and other resources important to the community. Essentially, the new site should improve the conditions that are causing the community to relocate in the first place.

Does the community move all at once?
The most likely scenario is that the community would not move all at once. Because of the high costs and difficult logistics, a community would realistically move over the course of time. The model that seems most practical is to start at the new site with a few homes and rudimentary infrastructure. Over time, more houses could be moved, with new infrastructure being built at the new site instead of upgrading or replacing facilities at the old. This will spread out the cost and the logistics over time. For a while, it would seem that there are two communities, but eventually, the new site would be the more desirable location for the community to have its permanent residence and the old site would no longer be maintained.

What is to be done with the existing site?
This is a particularly difficult issue especially in regard to any sites of cultural value or areas that may have potential contamination. Our estimates have included some costs for the decommissioning of the old site. Regarding access, it would be expected that the community would still have access to the old site for cultural or subsistence activities. It also may be reasonable to assume that a few families may still maintain a structure or residence at the old site. However, if a relocation effort is to be successful, then groups responsible for the development of housing and infrastructure must stop investing in the old site, and provide

resources only to the new. Eventually, the old site could be expected to be utilized as a remote subsistence camp similar to those scattered for miles around the area of the community.

Should the community be moved as-is or should it be upgraded to current standards?
The model we have used is that the relocation effort would move whatever structures can reasonably be moved and replace those that could not. For example, many of the existing houses are quite portable, but other items, such as the bulk fuel tanks, cannot be readily moved. If it would be less expensive to replace than move, then it would be replaced. Funds that would upgrade or replace a system at the old community would be used to build a new system at the new community.

What needs to happen first for relocation?
This issue acknowledges that there are several policies, regulations, and laws that state there must be X number of people in a community before item Y can be provided. The analysis of these regulations is beyond the scope of this study, but will be completed as part of the relocation planning.

What is the timeline for relocation?
Logistics and funding govern this issue. Practically speaking, it will take several years for a community to move. Only so much funding can be provided on an annual basis, and, because of the seasonal weather constraints, there is only so much time that work can be done in any given year. Through our analysis we determined that a timeline of 15 to 20 years for complete relocation is a reasonable expectation.

What costs are directly related to erosion and what are related to other issues?
Erosion issues are not the only reasons why communities want to relocate. Both Kivalina and Shishmaref have expressed that their communities have no room left to expand and that their current location has made it infeasible for them to have running water and sewer hookup. Erosion of land has much to do with why a community has little space to expand, but little to do with ability to have running water and sewer hookups.

What agency will take the lead for erosion and relocation?
The issue of there being no lead agency to administer a statewide erosion program has been mentioned at all levels of government. Indeed, no single agency has all the authorities, much less the funding, to relocate a community. The Corps recognizes this issue and, in the interim, has taken steps to lead the way for a number of discreet elements. For example, the Alaska Baseline Erosion Assessment, an activity to coordinate, plan and prioritize appropriate responses to erosion issues in Alaska, has been using a collaborative planning forum to accomplish project goals. The Corps has assumed a leadership role for coordination and technical analysis, which is being coordinated also through various Federal, State, Federally recognized Tribes, and local agencies. A similar lead agency model may work for addressing the overall issue of erosion in Alaska. In order to execute a program of this magnitude, it is essential that a lead agency be designated through authorization (or some level of empowerment), be provided specific direction, and granted access to a continuous funding stream. Utilizing an assemblage or bundling of agencies would likely hinder accomplishment of implementing a substantial project. Each agency typically has their own program , funding

priorities, authorities, and fiscal rules that often are not conducive to multi-agency cooperation efforts. A lead agency is essential to provide commitment, direction and unity of purpose. That lead agency would then be able to tap the skills and abilities of the other agencies to accomplish task within their fields of expertise.

Do existing programs have sufficient funding and authority to initiate a move?
There appears to be sufficient authority throughout several agencies that could build a new community and all its related infrastructure. However, orchestrating the efforts of multiple agencies to implement a well-coordinated relocation would be a significant challenge. Initiating relocation would likely take special authorization and funding to begin the process. The key issues are ensuring funding exists to finance the appropriate programs to assist in the move, and designating the lead agency to lead and coordinate the effort.

Is relocation worth the cost?
Using the Corps typical benefit/cost ratio is probably not appropriate for relocation analysis even though future damages and costs of erosion control and/or relocation are mentioned in this report. There are multiple non-monetary items that have yet to undergo a detailed analysis. These are social and cultural effects as a result of erosion that cannot easily be reflected in dollar damages. Potential negative effects are loss of independence, discrimination, lack of employment opportunities, competition for scarce subsistence resources, and hostile education environment. Adverse life, health, and safety issues include loss of tribal entity, loss of language, increased health risks, and perceived safety in the new location.

What effect does climate change have upon the issue of erosion in Alaska?
For many, climate change seems to be the key issue at the center of Alaska erosion issues. The actual effects are unknown at this time but the issue does appear to have significant influence over erosion issues for coastal communities.

A noticeable physical parameter of climate change has been the late forming shore fast ice at locations along the Bering Strait and Chukchi Sea. Sea ice is particularly important during the autumn months when large Artic Ocean storms create waves and storm surge that cause erosion damage to communities typically protected by sea ice. Though the Corps has not investigated the extent of sea ice change, the National Snow and Ice Data Center (NSIDC) has published a trend in reduction of sea ice.

Regarding riverine communities, the effects of climate change and its impacts on erosion have not been investigated by the Corps. A significant factor could be the presence of permafrost in river banks. If permafrost were to become depleted, the river banks could lose stability and become more susceptible to erosion damages.

As the Corps continues to address erosion issues in Alaska, scenario analysis regarding climate trends will become an integral part of the decision making process. In particular, future planning and designs will need to examine various scenarios involving permafrost and sea ice to ensure designs can adapt to the various potential changes.

4.2. Methodologies for Responding to the Three Questions

The following sections detail the specific methodologies we utilized to answer the three questions posed by congress. We attempted to analyze the various communities utilizing the same basis and assumptions, but there always will be differences between each community and how community specific issues are to be addressed. With that in mind, the three questions were answered as follows.

4.2.1. What are the costs associated with continued erosion of these communities?

Question one examines the continued cost of erosion, which can be widely varied depending upon what exactly is being examined. Costs can include damages incurred by erosion, ongoing maintenance of protection structures, what it may cost to install erosion protection, and what are the social and income losses associated with the erosion problem.

For this analysis, the ongoing costs of erosion are broken into three categories:

- *Costs of protective measures installed to date.* This will include any constructed erosion protection project such as revetments, sheet-pile walls, and any emergency erosion protection measures undertaken.

- *Cost of future damages.* The future costs will examine the predicted losses due to future erosion damages. For communities such as Bethel, where much of the shoreline has been protected, this number will be low.

- *Cost of future erosion protection projects.* This category will include expected future construction of new erosion protection projects. Operation and maintenance is also a cost of erosion protection; however, past experience has shown us that operations and maintenance (O&M) is sometimes not actually performed especially if the O&M responsibilities are assigned to a local entity that already has enough financial responsibility as it is. A value for what the costs of future anticipated erosion protection would be, assuming the community either has it planned, requires it for the interim, or would need it if not relocated, has been included in the community specific discussion sections.

Erosion protection efforts to date are somewhat difficult to determine. Information is not always readily available and some erosion expenditures (especially emergency efforts) are undertaken at a local level. Records of those efforts were not available for this study. The following table summarizes data obtained from the Alaska Department of Commerce Community and Economic Development and Corps records for past erosion control efforts in the seven communities that are the subject of this report. Almost $74 million have been expended since 1981 in erosion control efforts for these communities.

Table 1 lists erosion control efforts for the seven listed communities. Table 2 lists other recent erosion control efforts undertaken by the Corps in other Alaskan communities.

Table 1. Summary of Erosion Control Measures Already Implemented

	State of AK Grants	Corps of Engineers	Natural Resources Conservation Service	DOT&PF	Bureau of Indian Affairs
Bethel	$23,493,000	$22,700,000		$4,760,000	
Dillingham		6,100,000			
Kaktovik					
Kivalina	485,000				
Newtok	1,477,000				
Shishmaref	1,715,000	1,500,000		90,000	5,200,000
Unalakleet	1,807,000		1,300,000	180,000	
Total by Funding Source	**$28,977,000**	**$34,300,000**	**1,300,000**	**$5,030,000**	**$5,200,000**

Note: DOT&PF is the State of Alaska Department of Transportation and Public Facilities.

Table 2. Summary of Other Recent Corps Erosion Control Measures

Project Title	Completed	Cost	Description
Deering Streambank Protection	1997	0.7M	Revetment totaling 1,379 lf
Emmonak Streambank Protection	1998	1.2M	Revetment totaling 1,452 lf
Galena Emergency Bank Stabilization	2005	3.9M	Revetment totaling 1,590 lf
Homer Spit Erosion	1998	8.4M	Revetment totaling 4,830 lf
Metlakatla	1995	0.2M	Revetments totaling 1,239 lf

4.2.2. What are potential costs associated with moving the affected communities to new locations or an existing community?

Question two examines the cost difference between moving a village to a new location and co-locating a village with an existing community. As demonstrated previously in the discussion of assumptions, this is an extremely difficult question to answer. Just stating a dollar figure alone does not encapsulate the various costs associated with moving a village. The analysis we performed developed a cost that includes all funds anticipated to be spent by all Federal, State, and local entities to move what can be moved and replace what cannot be moved, in a new location.

To answer the second question, the cost of relocation, three values were investigated:
The first value is the cost of relocating the entire community to a new site, including all the existing facilities, structures, and utilities that can be moved and replacement of those that

cannot be moved. We assumed communities would be relocated as is. For example, if a village does not have running water at its existing site, it will not have it at the new location under the assumptions of our analysis. Specific numbers were developed for the three communities most expected to relocate.

The second value is the cost of moving a village to an existing community, typically a regional hub such as Nome, Kotzebue, or Bethel. The co-location would include providing similar amenities to those currently afforded in the hub community. For example, Nome residents have running water; therefore, members of the village being co-located would also have running water. For this analysis, a detailed cost of moving Shishmaref to Nome or Kotzebue was developed. A co-location number for Kivalina was found by scaling the Shishmaref-Kotzebue collocation cost number by the ratio of population in Kivalina to Shishmaref. Similarly, the co-location number for Newtok was found by scaling the Shishmaref-Nome collocation cost by the ratio of the population in Newtok to Shishmaref. This is a rough comparison; however, in our analysis of co-location costs for Shishmaref, the driving factor in the costs was population of individuals being moved into the community of question, thus making the population ratio a reasonable assumption.

We also found that co-locating a community into a neighboring village was almost the same as starting a new community from scratch. Most of the neighboring communities have facilities that are near capacity at best and would require extensive upgrades to make that type of co-location possible.

The third value is an estimate of what it would take to homestead a new community in a new location. This option would have a small group of houses moved or constructed at a mainland site, with no infrastructure support, in similar fashion to the relocation currently being attempted in Newtok, Alaska. More gradually than the phased move, the new community would begin to take root and would eventually qualify for power, schools, runway, etc. Over time, the new community would be allowed to thrive, and the old systematically abandoned.

The values in this document are intended to provide a range or an order of magnitude value from which a comparison of different types of actions can be made.

4.2.3. What is the expected time line for a complete failure of the usable land associated with each community?

The final question was analyzed by using a combination of aerial photography and ground measurements to track the rate of erosion over time, then assuming that rate continues, determines the erosion line be in the future. This methodology has shortfalls. For example, it assumes that the community would do nothing to protect itself, that the soils are basically the same composition as they go farther inland, and that the forces contributing to the erosion would remain constant over the period of future analysis. What this analysis does is show the potential ranges of erosion if left unchecked.

The determination of what is usable land is also subjective. For the sake of this analysis, we assume that if a significant portion of the critical infrastructure in a community (the school, the

power plant, the water supply) was left unusable, then the community would have to relocate by default and seek refuge in other communities.

For each community, a recent aerial photograph showing historic shorelines and projected shorelines is included, as well as an estimate of how long the community has left until sufficient infrastructure has been lost to make seeking refuge the only option available.

5.0 COMMUNITY SPECIFIC INFORMATION

The following sections contain information relative to each community regarding answers to the three questions. Section 5.8 contains tables that summarize the information for all the communities. The discussions include information on demographics, employment, infrastructure, school enrollment, and other data that will help the reader develop a feeling for the affected communities. Figure 1 shows the location of each of the seven communities investigated.

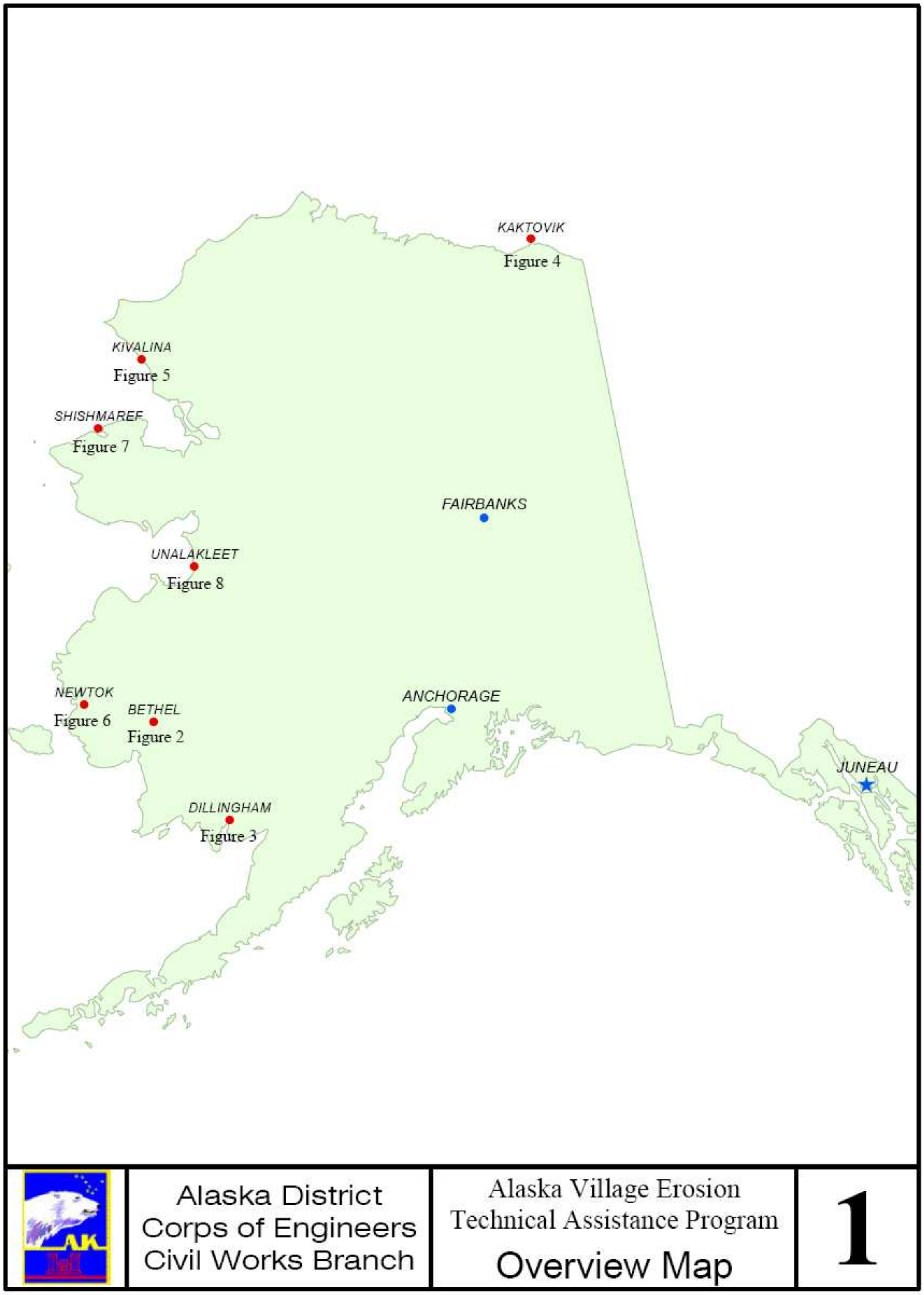


Figure 1 – Community Locations

5.1 Bethel

5.1.1. Community Information

Bethel is located along the Kuskokwim River, 40 miles inland from the Bering Sea. It is in the Yukon Delta National Wildlife Refuge, 400 air miles west of Anchorage. The community is at approximately 60° North Latitude and -161° (West) Longitude (Sec. 09, T008N, R071W, Seward Meridian.) Bethel is in the Bethel Recording District. The area encompasses 43.8 square miles of land and 5.1 square miles of water. Precipitation averages 16 inches a year in this area and snowfall averages 50 inches per year. Summer temperatures range from 42 to 62 degrees Fahrenheit. Winter temperatures range from -2 to 19 degrees Fahrenheit.

Beach landing at Bethel

Example of Bethel shoreline

5.1.2. What are the costs associated with continued erosion?

Three elements are associated with erosion costs: past protection endeavors, the cost of ongoing repair and maintenance, and future damages. These are discussed in more detail in the following paragraphs.

5.1.2.1. Erosion Protection Costs

Bethel is approximately 65 miles upriver from the mouth of the Kuskokwim River and is at the upriver limit of tidal influence from the Bering Sea. Bethel is the major educational, economic, social, and cultural community in the Southwest Alaska Region, serving numerous smaller villages along the Yukon-Kuskokwim River Delta. For the last 40 years the riverbank adjacent to the community has been seriously eroded.

Bethel experiences periodic flooding, mostly because of ice jams during the spring breakup of the Kuskokwim River. The spring ice breakup in 1995 caused such severe erosion that the governor of Alaska declared a state of emergency—scour created a cove 350 feet long and 200 feet inland and endangered several structures. The village's main port is the only one on the western Alaska coast for oceangoing ships and serves as the supply center for villages in the Yukon-Kuskokwim Delta. In response to the 1995 emergency, the Corps placed rock along 600 linear feet of the riverbank and dock.

Riverbank Protection at Bethel

Looking other direction

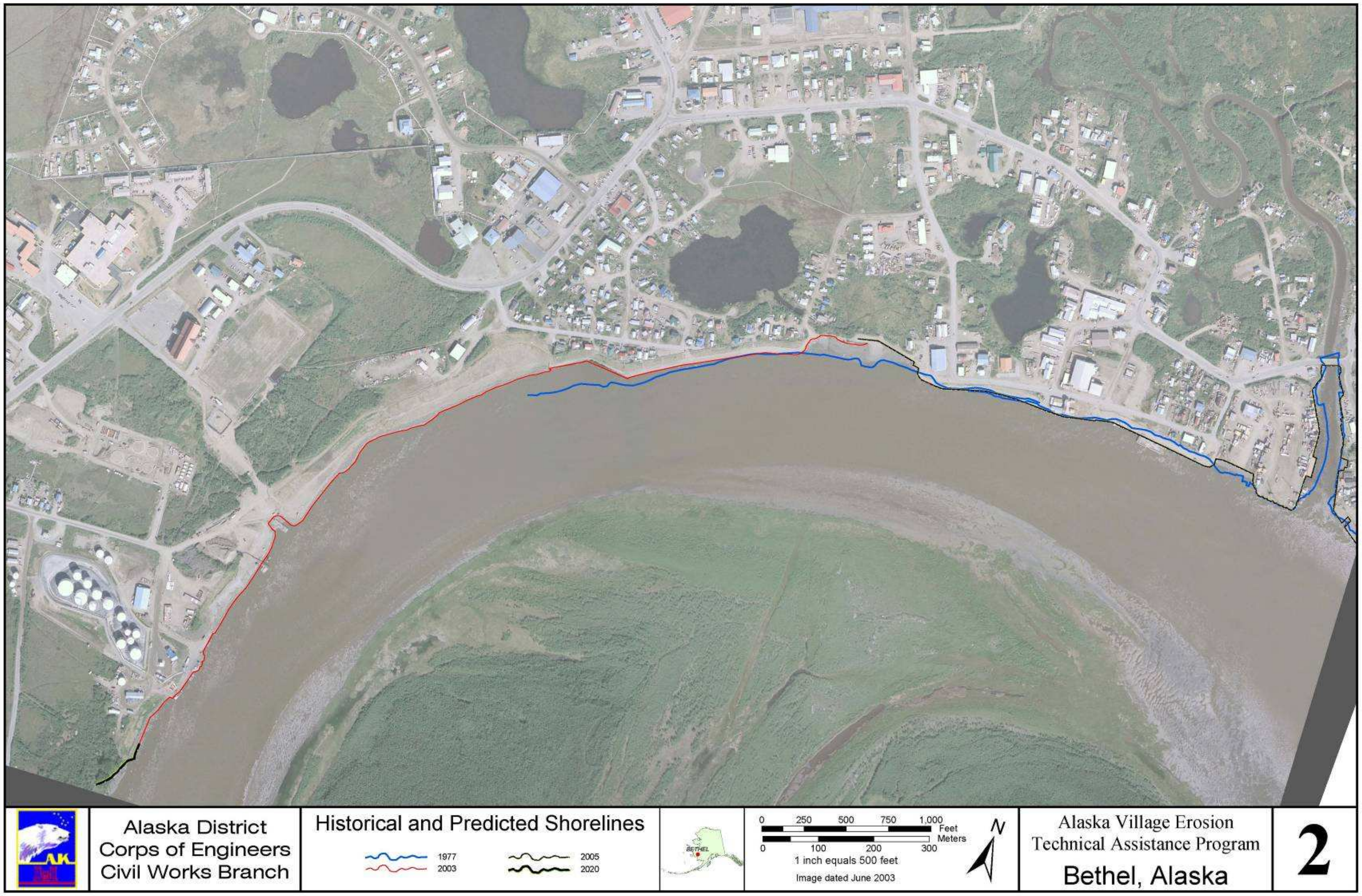
This was the beginning of a Corps 8,000-foot bank stabilization seawall project that cost $24 million and was completed in 1997. This project included stabilization of the riverbank from the existing petroleum dock at the downstream end to the Bethel city dock at the upstream end.

Although Bethel is not in imminent danger, it has experienced serious erosion and has undertaken various infrastructure-specific activities to resolve this problem. The Corps has a project underway to repair the seawall by placing more rock, by replacing a steel tieback system, and placing steel wale on the inland side of the pipe piles. The project will reinforce the seawall 1,200 feet so that it protects the entrance to Bethel's small boat harbor. The initial cost estimate for this project in 2001 was over $4.7 million. The project should be completed in 2006. Because of these measures, there are no plans for Bethel to relocate or collocate to another site.


Pile wall of current concern at Bethel.

Obvious outward bowing of wall.

Erosion control efforts by the State of Alaska legislative grants and Department of Transportation and Planning Formulation (DOT&PF) funds, Corps, and Federal Aviation Association (FAA) to date total more than $57 million.


Alaska District
Corps of Engineers
Civil Works Branch
Historical and Predicted Shorelines
1977
2003
2005
2020
0 250 500 750 1,000 Feet
0 100 200 300 Meters
1 inch equals 500 feet
Image dated June 2003
N
Alaska Village Erosion
Technical Assistance Program
Bethel, Alaska
2

5.1.2.2. Future Damages

Future erosion damages are expected to be minimal because of the existing 8,000-foot bank stabilization seawall, which is undergoing repairs that will extend the life of the project.

5.1.3. What are potential costs associated with moving to a new location or an existing community?

There is no reasonable need for Bethel to relocate. With the exception of a few small segments, the erosion at Bethel has been contained. The rest of the erosion is currently being addressed through other means. In addition, the community and state have not expressed interest in relocating Bethel; therefore, numbers for relocation were not developed.

5.1.4. What is the expected time line for a complete failure of the usable land?

With proper maintenance, the existing and planned projects should provide adequate erosion protection well into the future. No time line is provided because complete failure of the usable land is highly unlikely in the short or long term.

Table 3 - Summarized Information for Bethel

Community	Costs of Future Erosion Protection	Cost to Relocate	How Long Does The Community Have*
Bethel	$ 5,000,000	N/A	> 100 years

*These numbers assume no future erosion protection, including that listed here, is not implemented

5.2. Dillingham

5.2.1. Community Information

Dillingham is at the extreme northern end of Nushagak Bay in northern Bristol Bay at the confluence of the Wood and Nushagak rivers. It is 327 miles southwest of Anchorage and is a 6-hour flight from Seattle. The community is at approximately 59° North Latitude and -158° (West) Longitude (Sec. 21, T013S, R055W, Seward Meridian.). Dillingham is in the Bristol Bay Recording District. The area encompasses 33.6 square miles of land and 2.1 square miles of water. The primary climatic influence is maritime; however, the arctic climate of the Interior also affects the Bristol Bay coast. Average summer temperatures range from 37 to 66 degrees Fahrenheit. Average winter temperatures range from 4 to 30 degrees Fahrenheit. Annual precipitation is 26 inches, and annual snowfall is 65 inches. Heavy fog is common in July and August. Winds of up to 60 to 70 mph may occur between December and March. The Nushagak River is ice-free from June through November.

View of downtown Dillingham

Corps shore protection at Snag Point

5.2.2. What are the costs associated with continued erosion?

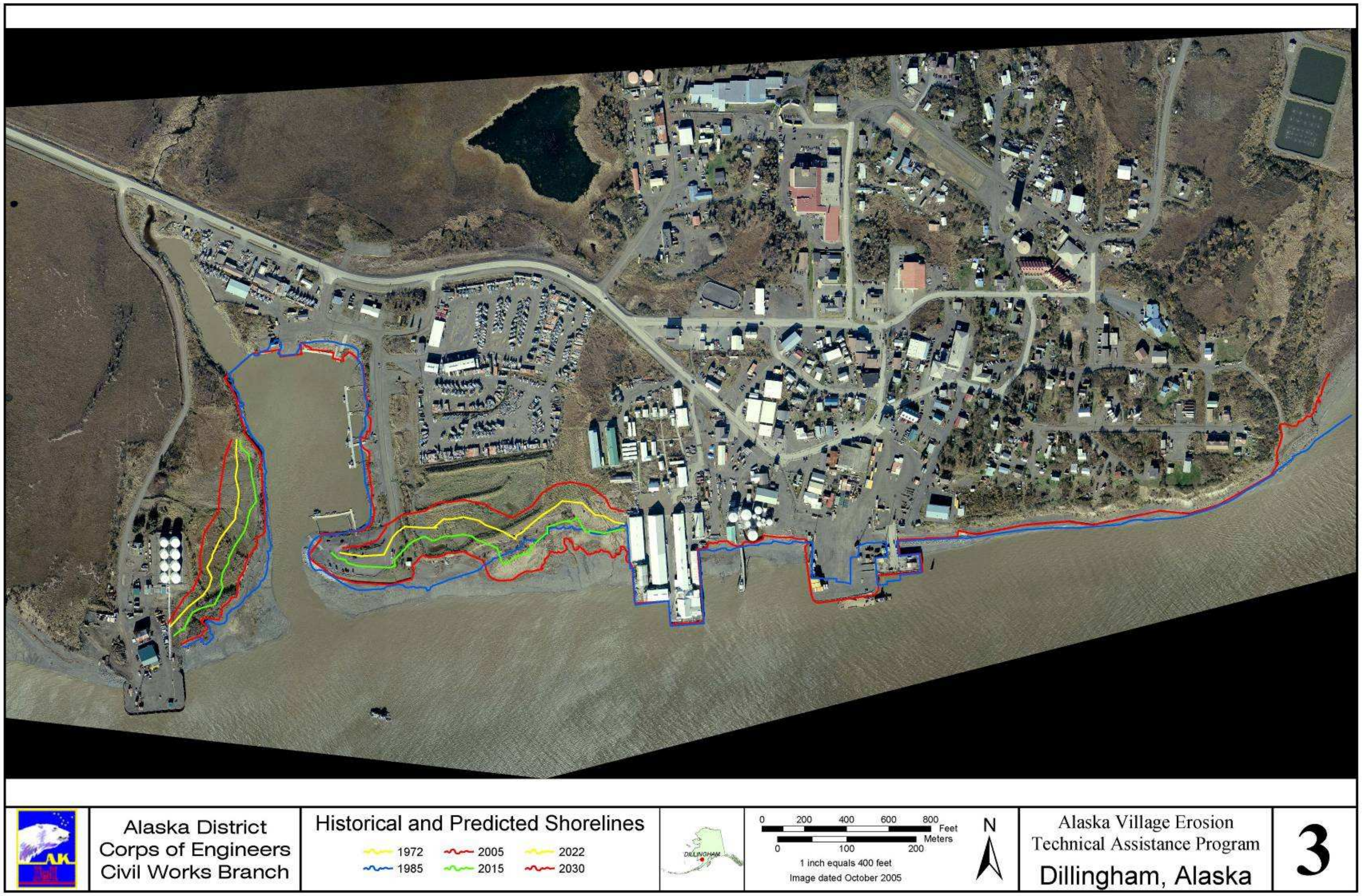
There are three elements related to costs associated with erosion: past protection endeavors, the cost of ongoing repair and maintenance, and future damages. These are discussed in more detail in the following paragraphs.

5.2.2.1. Erosion Protection Costs

Previous efforts to control riverbank erosion near the small boat harbor consisted of timber plank and pile bulkheads built in 1983 by the City of Dillingham at Snag Point, about ¾ mile east of the small boat harbor; 1,600 feet of sheet-pile bulkhead built by the Corps at Snag Point between 1995 and 1998 (COE 1995, 1997); and about 600 feet of sheet-pile bulkhead built by the Corps immediately east of the harbor entrance in 1999 (COE 1998). In addition, Bristol Alliance Fuels has installed a sheet-pile wall to protect their mooring facilities. Erosion control efforts by the Corps to date total more than $6 million.

Storm waves entering Dillingham Harbor

Corps protection on harbor east bank


Alaska District
Corps of Engineers
Civil Works Branch
Historical and Predicted Shorelines
1972
1985
2005
2015
2022
2030
DILLINGHAM
0 200 400 600 800 Feet
0 100 200 Meters
1 inch equals 400 feet
Image dated October 2005
N
Alaska Village Erosion
Technical Assistance Program
Dillingham, Alaska
3

A project to protect Dillingham Harbor and the surrounding facilities is nearing completion of the planning phase and the beginning of the design phase. Typical annual storms are causing land to erode along the west bank of Dillingham Harbor. As seen in the photos above, the waves enter the harbor and continually erode the west bank. The east bank has already been protected by a Corps project. Erosion at the west side of the harbor entrance is also fueled by wave action in conjunction with high tides. Currently, the west bank of Dillingham Harbor is eroding at an average rate of 11 feet per year. If left unchecked, the continued erosion would lead to a significant decrease of harbor protection. In addition to reduced bank protection for the harbor, floats, and commercial fishing fleet, land as well as the majority of the fuel supply for the area would be lost. Construction of this project is scheduled for 2007.

5.2.2.2. Future Damages

It is expected that future erosion damages are expected to be minimal because of the existing bank stabilization seawall and the proposed erosion protection project at the east and west bank of the harbor.

5.2.3. What are potential costs associated with moving to a new location or an existing community?

There is no reasonable need for Dillingham to relocate. With the exception of a few small segments, the erosion at Dillingham has been contained. The rest of the erosion is currently being addressed through other means. In addition, the community and State have not expressed interest in relocating Dillingham; therefore, numbers for relocation were not developed.

5.2.4. What is the expected time line for a complete failure of the usable land?

Complete failure of the Dillingham property is not expected in the foreseeable future. Some erosion control measures are already in place, removal and reburial of grave sites is already occurring, and other measures are underway.

Table 4 - Summarized Information for Dillingham

Community	Costs of Future Erosion Protection	Cost to Relocate	How Long Does The Community Have*
Dillingham	$ 10,000,000	N/A	> 100 years

*These numbers assume no future erosion protection, including that listed here, is not implemented

5.3. Kaktovik

5.3.1. Community Information

Kaktovik is on the north shore of Barter Island between the Okpilak and Jago Rivers on the Beaufort Sea coast. It is the only community within the boundaries of the Arctic National Wildlife Refuge, which is 19.6 million acres and an occasional calving ground for the Porcupine caribou herd. The community is at approximately 70° North Latitude and -143° (West) Longitude (Sec. 13, T009N, R033E, Umiat Meridian). Kaktovik is in the Barrow Recording District. The area encompasses 0.8 square mile of land and 0.2 square mile of water. The climate of Kaktovik is arctic. Temperatures range from -56 to 78 degrees Fahrenheit. Precipitation is light, at 5 inches, with snowfall averaging 20 inches.

The Village of Kaktovik

Shoreline Erosion

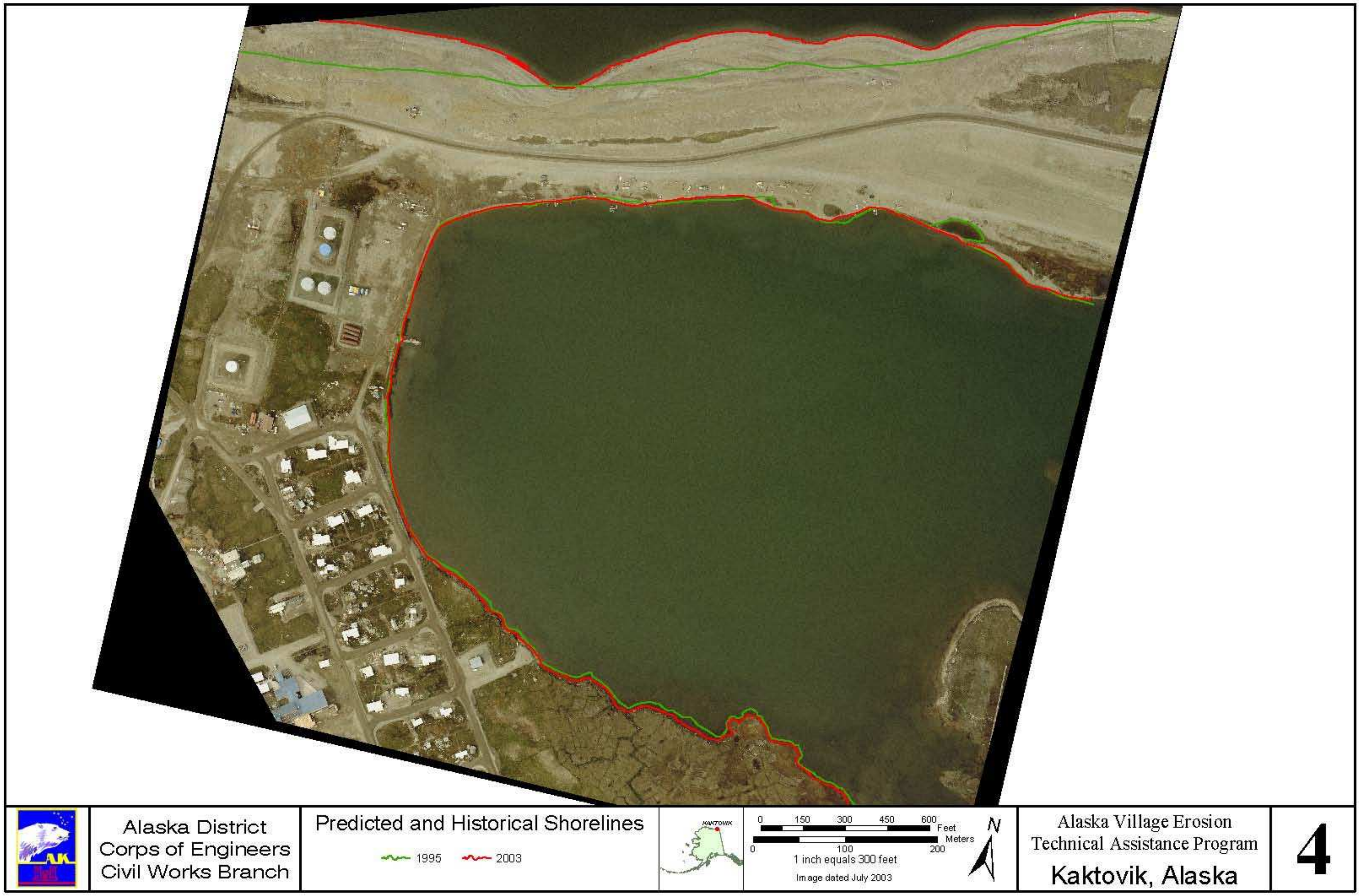
5.3.2. What are the costs associated with continued erosion?

There are three elements related to costs associated with erosion: past protection endeavors, the cost of ongoing repair and maintenance, and future damages. These are discussed in more detail in the following paragraphs.

5.3.2.1. Erosion Protection Costs

Shoreline Erosion

The only notable erosion that has had a direct effect on the community is along the frontage within the lagoon (Pipsuk Bight). Protection of this area was provided in the 1990's by construction of a timber crib wall. This structure has performed well and has essentially stabilized the area such that erosion is not a problem for the community along this portion of the lagoon.



Alaska District
Corps of Engineers
Civil Works Branch
Predicted and Historical Shorelines
1995
2003
0 150 300 450 600 Feet
0 100 200 Meters
1 inch equals 300 feet
Image dated July 2003
N
Alaska Village Erosion
Technical Assistance Program
Kaktovik, Alaska
4

The existing airstrip is on the low elevation sand spit immediately north of the community. Erosion protection measures have been constructed in the past along the seaward edge of the airstrip. Recent surveys and aerial photography indicate that the airstrip is stable. Flooding due to storm surge increases in water surface elevation is an ongoing problem during open water storm season.

The U.S. Air Force Long Range Radar Site (LRRS) is immediately west of the community of Kaktovik. Numerous buildings, fuel tanks, a sewage lagoon, and an old landfill are located there. The northern limits of this site are directly exposed to the wave action in the Beaufort Sea. A gravel bag revetment was designed by the Corps and constructed in 1999 along with a groin field to build a beach in front of the revetment to reduce the amount of wave energy at this site.

Corps Gravel Bag Revetment in1999

Revetment in 2003

Four sites in the vicinity of Kaktovik eligible for listing on the National Register of Historic Places are affected by erosion. Artifacts eroded from these areas are being lost. Local government agencies and members of the community are concerned about the loss of artifacts and history associated with this area. Without the protection of the sites or documentation and preservation of the artifacts, valuable information will be lost, which will reduce our understanding of the history of the culture along the coastal community in the Arctic National Wildlife Refuge (ANWR).

5.3.2.2. Future Damages

With the exception of the airport and cultural resources, the community of Kaktovik is not experiencing significant damages such as erosion, wave attack, or flooding from coastal storms. There have been no reports of damaged or destroyed infrastructure or buildings from coastal storms with the exception of a snow fence west of the community. Minor erosion in Kaktovik Lagoon was reported, but would not pose any threat for at least 100 years.

Airport

If a new airport is constructed, this would eliminate the erosion and flood damages the current airport is experiencing. Protection for the existing runway is estimated to cost approximately $40 million.

Cultural Sites

For centuries, as the name implies, trade has been conducted at Barter Island between people along the Beaufort Sea coast from Barrow to central Canada. The people of Kaktovik trace their roots to many areas of northern Alaska and Canada. The *Archaeological Evaluation of Cultural Resources* Near Kaktovik, Barter Island, Alaska prepared in October 2004 recommended the site Qaaktugvik be examined for the National Register of Historic Places as a traditional cultural property. This parcel is in danger of being lost to erosion. Because of its significance, the Corps is undertaking a study to more closely examine and catalog the area.

Summary of Erosion Costs

Protection of the airport would be approximately $40 million. Because of the unknown quantity and quality of artifacts, and the inherent difficulties in assigning a monetary value to an item of cultural significance, the costs of damages to the cultural sites has not been determined.

5.3.3. What are potential costs associated with moving to a new location or an existing community?

There is no reasonable need for Kaktovik to relocate. With the exception of the airport and a few small segments, the erosion at Kaktovik has been contained. In addition, the community and State have not expressed interest in relocating Kaktovik; therefore, numbers for relocation were not developed. The cost to relocate the airport at Kaktovik is estimated at $20 to $40 million

5.3.4. What is the expected time line for a complete failure of the usable land?

Though there are some localized areas of concern (the airport and cultural sites) erosion is not expected to cause failure of the community within the foreseeable future (hundreds of years).

Table 5 - Summarized Information for Kaktovik

Community	Costs of Future Erosion Protection	Cost to Relocate	How Long Does The Community Have
Kaktovik	$ 40,000,000 *	$20 – 40 million *	> 100 years

*This is for the airport, the only area of erosion concern.

5.4. Kivalina

5.4.1. Community Information

Kivalina is at the tip of an 8-mile barrier reef located between the Chukchi Sea and Kivalina River. It is 80 air miles northwest of Kotzebue. The community is at approximately 67° North Latitude and -164° (West) Longitude, (Sec. 21, T027N, R026W, Kateel River Meridian.). Kivalina is in the Kotzebue Recording District. The area encompasses 1.9 square miles of land and 2.0 square miles of water. The community is in the transitional climate zone, which is characterized by long, cold winters and cool summers. The average low temperature during January is -15 degrees Fahrenheit, and the average high during July is 57 degrees Fahrenheit. Temperature extremes have been measured from -54 degrees Fahrenheit to 85 degrees Fahrenheit. Snowfall averages 57 inches, with 8.6 inches of precipitation per year. The Chukchi Sea is ice-free and open to boat traffic from mid-June to the first of November.

Kivilina shoreline with skiffs

Typical structures in Kivilina

Undermined building on Kivalina

Emergency shoreline protection - 2005


Alaska District
Corps of Engineers
Civil Works Branch
Predicted and Historical Shorelines
1975
1990
1997
2000
2010
2020
2030
0 150 300 450 600 Feet
0 100 200 Meters
1 inch equals 300 feet
Image dated August 2000
N
Alaska Village Erosion
Technical Assistance Program
Kivalina, Alaska
5

What are the costs associated with continued erosion?
There are three elements related to costs associated with erosion: past protection endeavors, the cost of ongoing repair and maintenance, and future damages. These are discussed in more detail in the following paragraphs.

5.4.1.1. Erosion Protection Costs

Kivalina has not historically seen significant erosion. The Kivalina spit has seen cyclic erosion and accretion, with modest accretion on the Chukchi Sea side more prevalent during the 30-year period of 1970 to 2000. The higher energy storms that could result in significant erosion occur during the winter months when the Chukchi Sea is frozen. This has resulted in natural erosion protection in the past. However, with global climate change the period of open water is increasing and the Chukchi Sea is less likely to be frozen when damaging winter storms occur. Winter storms occurring in October and November of 2004 and 2005 have resulted in significant erosion that is now threatening both the school and the Alaska Village Electric Cooperative (AVEC) tank farm. This erosion has resulted in the loss of some teacher housing and the school and community washateria drain fields. Erosion control efforts by the state from 1985 to 2002 totaled $477,000, and during the last two years emergency erosion control efforts have cost approximately $850,000.

5.4.1.2. Cost of New Shoreline Protection

Due to the significant erosion of the last 2 years, emergency erosion protection is being pursued by both the State and Federal governments. The Northwest Arctic Borough (NWAB) is seeking $2.93 million to construct an erosion control structure at Kivalina to protect the tank farms. The NWAB hopes to construct this emergency protection during the summer of 2006. The Corps is currently investigating interim erosion protection for the community of Kivalina, recognizing that there will likely be a significant timeline associated with moving a community. Though detailed designs have not been developed, based on recent experience in other communities, e.g. Shishmaref, an 800-foot-long erosion protection structure to protect the school and AVEC tank farms is estimated to cost $8 million, while a more significant interim erosion protection structure to protect the full community is estimated to cost about $15 million.

5.4.1.3. Future Damages

The approach used to determine potential erosion damages at Kivalina is based on several assumptions as they pertain to the damage categories of residential, commercial, public infrastructure, and land values. In addition, damages are based on an assumed rate of erosion. These damages are those that would occur should the erosion protection not be installed or the community not relocate.

Residential Structures Assumptions

Oceanfront properties are assumed to fail in the 10-year project horizon and the rest of the village is assumed to fail in the 20-year project horizon. It is assumed that as erosion approaches individual homes, homeowners will take steps to salvage their personal property. With nowhere to move the structures, once the erosion reaches them, they will be a complete loss.

Commercial and Public Buildings Assumptions

The Kivalina Native Store and warehouse are the primary commercial structures in the community. While the store and warehouses are moveable, the lack of available land precludes relocation.

Infrastructure Assumptions

Roads, utility lines, the sewage lagoon, and solid waste site construction are based on the recent Shishmaref study with a discount for the smaller Kivalina population.

5.4.1.4. Summary of Future Damages

If no bank protection structures were to be installed, the combined residential, commercial, and public buildings and infrastructure costs due to erosion at Kivalina total more than $105 million for the 20-year project horizon, although the community will become uninhabited long before complete loss occurs.

5.4.2. What are potential costs associated with moving to a new location or an existing community?

The community has long assumed that the island would succumb to natural forces, and that they would have to move. To this end, residents have pursued relocation for the last 20 years. Their efforts have been stymied by difficulties in choosing a new village site, funding the relocation effort, and social problems within the village stemming from overcrowding, poverty, and other difficult living conditions.

Kivilina has yet to determine if they are going to relocate and where they would relocate to, which makes it difficult to estimate what the relocation costs would be. In addition, some of the sites selected by some in the community would require a significant amount of fill to be brought in, which would costs hundreds of millions of dollars, making those sites infeasible. The following, however, are preliminary estimates based upon finding a site requiring little or no fill to raise it above flood levels.

A relocation of the community to a new location would cost an estimated $123.4 million, which would include a minimal level of housing, water, and sanitation facilities.

A co-location to Kotzebue, the nearest hub community, would cost an estimated $95 million. This information is based upon a 2004 preliminary cost of alternatives for co-locating Shishmaref to Kotzebue, scaled to reflect the difference in population for Shishmaref and Kivalina.

5.4.3. What is the expected time line for a complete failure of the usable land?

The winter storms of 2004 and 2005 eroded 70 to 80 feet of uplands behind the school. The bank line is now within 25 feet of the main school structure. Erosion in the vicinity of the AVEC tank farm is similar, with only 5 feet of uplands remaining between the nearest tanks and the bank line. Without the construction of emergency erosion control structures, the school and tank farm will begin to fail within the next year if erosion continues at the same rate as it has during recent months,. Even if erosion slows, these critical structures are in imminent danger and are unlikely to survive for any extended period of time. Due to the physical lack of open land in the Kivalina community, these structures can not be relocated, and their failure would render the community uninhabitable.

Table 6 - Summarized Information for Kivalina

Community	Costs of Future Erosion Protection	Cost to Relocate	How Long Does The Community Have*
Kivalina	$ 15,000,000	$95 – 125 Million	10 – 15 years

*These numbers assume no future erosion protection, including that listed here, is not implemented

5.5. Newtok

Newtok is on the Ninglick River north of Nelson Island in the Yukon-Kuskokwim Delta Region. It is 94 miles northwest of Bethel. The community is at approximately 60° North Latitude and -164° (West) Longitude (Sec. 24, T010N, R087W, Seward Meridian). Newtok is in the Bethel Recording District. The area encompasses 1.0 square mile of land and 0.1 square mile of water. Newtok has a marine climate. Average precipitation is 17 inches, with annual snowfall of 22 inches. Summer temperatures range from 42 to 59 degrees Fahrenheit; winter temperatures are 2 to 19 degrees Fahrenheit.


Typical Newtok Erosion


The Village of Newtok

5.5.1. What are the costs associated with continued erosion?

There are three elements related to costs associated with erosion: past protection endeavors, the cost of ongoing repair and maintenance, and future damages. These are discussed in more detail in the following paragraphs.

5.5.1.1. Erosion Protection Costs

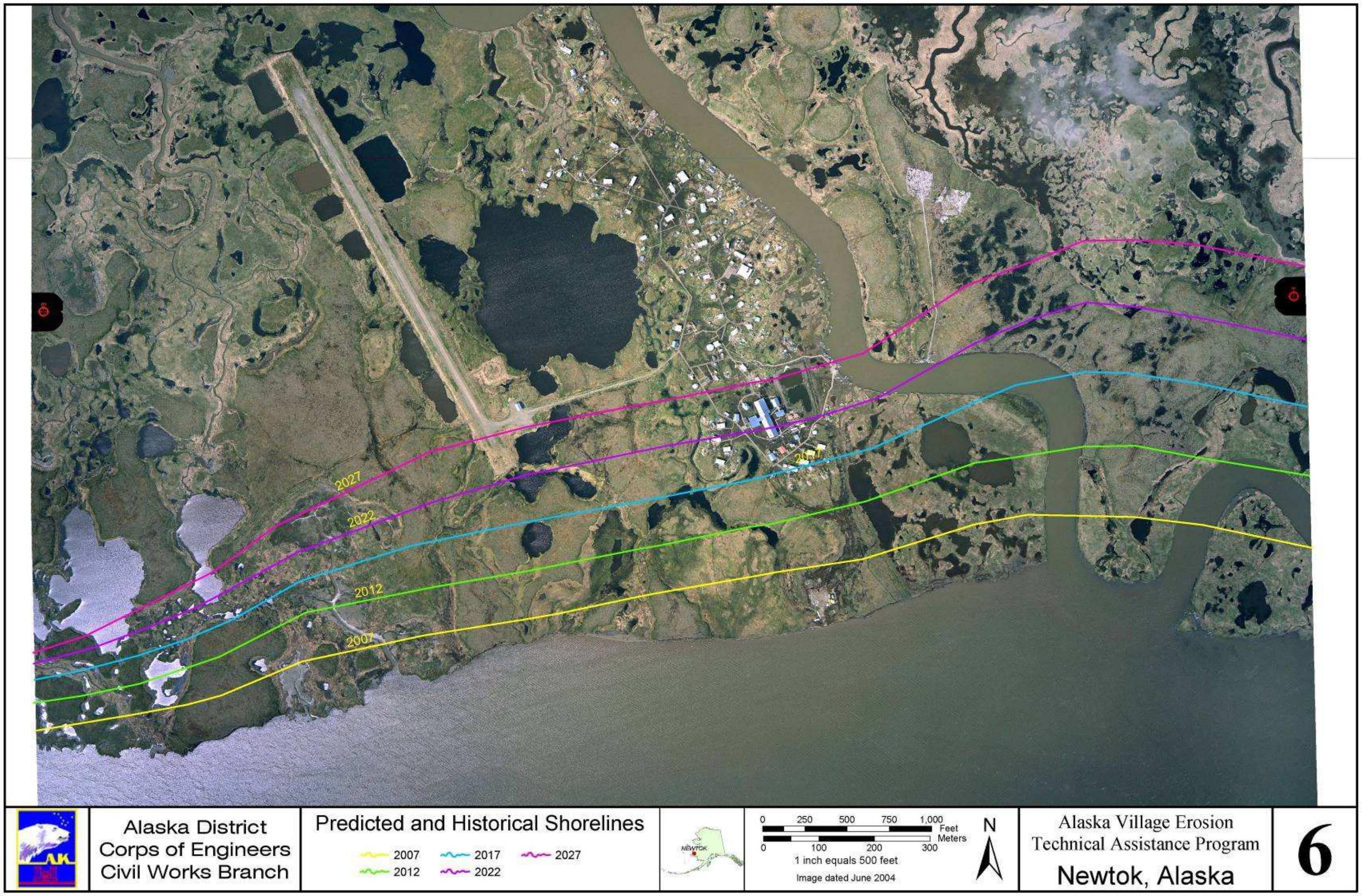
The Ninglick River has been eroding and moving in the direction of Newtok for decades. There are no geologic or channel geometry limitations evident that will slow down or stop the erosion before it reaches Newtok. Erosion control efforts by the state from 1983 to 1989 totaled almost $1.5 million.

5.5.1.2. Cost of New Shoreline Protection

To protect Newtok from further erosion would require a 5,280-foot-long erosion revetment. Construction costs are estimated at $90 million.

5.5.1.3. Future Damages

The approach used to determine potential erosion damages at Newtok is based on several assumptions as they pertain to the damage categories of residential, commercial, public infrastructure, and land values. In addition, damages are based on an assumed rate of erosion. These damages are those that would occur should the erosion protection not be installed or the community not relocate.


2027
2022
2012
2007
Alaska District
Corps of Engineers
Civil Works Branch
Predicted and Historical Shorelines
2007
2012
2017
2022
2027
NEWTOK
0 250 500 750 1,000 Feet
0 100 200 300 Meters
1 inch equals 500 feet
Image dated June 2004
N
Alaska Village Erosion
Technical Assistance Program
Newtok, Alaska
6

Residential Structures Assumptions

Some residential structures are expected to be lost in about 10 to 15 years with major loss in about 20 years. It is assumed that as erosion approaches individual homes, homeowners will take steps to salvage their personal property.

Commercial and Public Buildings Assumptions

Public buildings in Newtok include a health clinic, school, armory, church, the Traditional Council Office, Post Office, and Community Hall. Some of these may be able to move to a different location in town before being lost to erosion, but the majority of these would be reached by the erosion in 10 to 15 years.

Infrastructure Assumptions

Estimates were made concerning the boardwalks, electric lines, and water pipeline that would be lost as a result of erosion in the years prior to the lost over the next twenty years. Public utilities are considered a total loss in about twenty to twenty five years.

5.5.1.4. Summary of Future Damages

The combined residential, commercial, and public buildings and infrastructure costs due to erosion at Newtok are estimated to be more than $119 million for the 50-year project horizon.

5.5.2. What are potential costs associated with moving to a new location or an existing community?

In 1994, the Newtok Traditional Council started a relocation planning process in response to the erosion problem. The Council analyzed six potential village relocation sites, and a community vote in August 2003 overwhelmingly selected a site on the north end of Nelson Island, approximately 9 miles southeast of Newtok. This site is known locally as Takikchak. In January 2004 the Newtok Traditional Council provided a report prepared by the engineering firm ASCG, Inc, which documented the Council’s relocation planning process and site selection. This report included a geotechnical overview of the Takikchak site conducted by the Corps under the Planning Assistance to States (PAS) program.

Congress approved a land exchange between the Newtok Village Corporation and the U.S. Fish and Wildlife Service in 2003, under the Alaskan Native Village and the Interior Department Land Exchange Act of November 17, 2003, Public Law 108-129, 117 Stat. 1358. The Department of Interior conveyed 10,943 acres at the Takikchak site to the Newtok Village Corporation on April 28, 2004.

The community is actively working to establish a seed community in this new location by getting a few new Department of Housing and Urban Development (HUD) houses constructed at the new site.

To relocate Newtok “as-is” to the Nelson Island site would cost an estimated $125 million.

To collocate Newtok “as-is” with one of the nearby Nelson Island communities would cost an estimated $76 million.

5.5.3. What is the expected time line for a complete failure of the usable land?

According to work done by Woodward-Clyde Consultants, the erosion appears to be caused mainly by wave action and thermal degradation of the ice rich riverbank. The average long-term erosion rate in the Newtok area from 1957 to 2003 was estimated to be 71 feet per year. The minimum erosion rate for this period, which occurred from 1974 to 1977 and from 1999 to 2003, was 42 feet per year. The maximum erosion rate for this period, which occurred between 1977 and 1983, was 113 feet per year.

Based upon the erosion rates and the location of major utilities and infrastructure, the community will be a complete loss in 10 to 15 years.

Table 7 - Summarized Information for Newtok

Community	Costs of Future Erosion Protection	Cost to Relocate	How Long Does The Community Have*
Newtok	$ 90,000,000	$80 – 130 Million	10 -15 years

*These numbers assume no future erosion protection, including that listed here, is not implemented

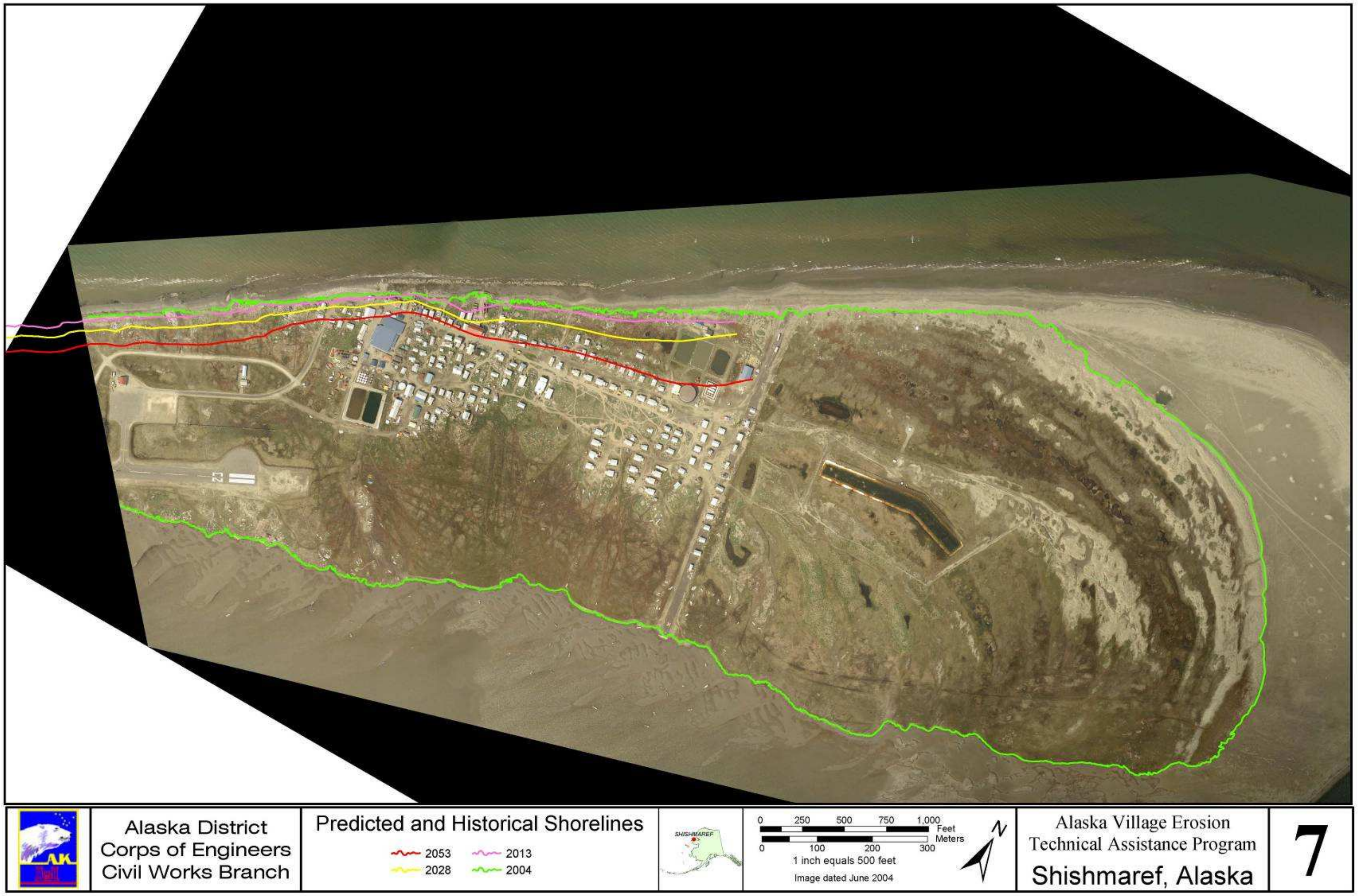
5.6. Shishmaref

5.6.1. Community Information

Shishmaref is on Sarichef Island in the Chukchi Sea, just north of Bering Strait. Shishmaref is 5 miles from the mainland, 126 miles north of Nome, and 100 miles southwest of Kotzebue. The village is surrounded by the 2.6 million-acre Bering Land Bridge National Reserve. It is part of the Beringian National Heritage Park, endorsed by Presidents Bush and Gorbachev in 1990. The community is at approximately 66° North Latitude and -166° (West) Longitude, (Sec. 23, T010N, R035W, Kateel River Meridian). Shishmaref is in the Cape Nome Recording District. The area encompasses 2.8 square miles of land and 4.5 square miles of water. The area experiences a transitional climate between the frozen arctic and the continental Interior. Summers can be foggy, with average temperatures ranging from 47 to 54 degrees Fahrenheit; winter temperatures average -12 to 2 degrees Fahrenheit. Average annual precipitation is about 8 inches, including 33 inches of snow. The Chukchi Sea is typically frozen from mid-November through mid-June, although in recent years freeze up has occurred later and thaw earlier.

The community of Shishmaref

Old articulated concrete mat project



Alaska District
Corps of Engineers
Civil Works Branch
Predicted and Historical Shorelines
2053
2013
2028
2004
0 250 500 750 1,000 Feet
0 100 200 300 Meters
1 inch equals 500 feet
Image dated June 2004
N
Alaska Village Erosion
Technical Assistance Program
Shishmaref, Alaska
7

5.6.2. What are the costs associated with continued erosion?

Three elements are associated with erosion costs: past protection endeavors, the cost of ongoing repair and maintenance, and future damages. These are discussed in more detail in the following paragraphs.

5.6.2.1. Historical Erosion Protection Costs

The community of Shishmaref is being affected by high rates of erosion along the shoreline. Climatic conditions have led to icepack development occurring later and later each year. Without the icepack in place, the island is more susceptible to fall and early winter storms that have increased erosion and littoral drift. Erosion and littoral drift are shifting the island footprint northeastward and southwestward, subjecting the developed areas to massive wave scour and erosion of the fine materials that make up the island. Erosion is undermining buildings and infrastructure, causing several structures to collapse and fall into the sea. All efforts to arrest the erosion have been unsuccessful for other than short periods of time.

Past protection attempts in 2003.

BIA protection in foreground in 2003.

Recently the Bureau of Indian Affairs (BIA), the City of Shishmaref, and the Corps have invested in shoreline protection along the community of Shishmaref. In 2004, the BIA installed 200 feet of shoreline protection along the shoreline near the Native store. In 2005, the Corps installed 230 feet of protection, connecting to the BIA project, extending to the east to protect the Shishmaref School. Also in 2005, the community of Shishmaref installed about 250 feet of protection extending to the east from the Corps project.

Post Fall 2004 Storm

Corps Project Under Construction in 2005

Post Construction – Corps Project to Right / City Project to Left in 2005

Erosion control efforts by the state (including legislative grants and Department of Transportation funding), Corps, and BIA to date total more than $9.5 million.

5.6.2.2. Cost of New Shore Protection

The Corps is also developing a project that will protect the remaining portions of shoreline as well as upgrade all the existing projects to the same standard of protection. The project is currently estimated to cost $16,000,000. This project will provide for consistent protection stretching along the entire community waterfront, not including the airport. The recently installed projects will provide some protection against the ongoing erosion problem. The city project could use an additional layer of armor stone and both the BIA and city project may need to be elevated, but both should provide adequate protection until the remainder of the Corps project can be built. Protecting the airport may require additional effort.

5.6.2.3. Future Damages

The approach used to determine potential erosion damages at Shishmaref is based on several assumptions as they pertain to the damage categories of residential, commercial, public infrastructure, and land values. In addition, damages are based on two different rates of erosion. An examination of the erosion rates based on aerial photos from 1973 to 2003 show a somewhat subdued rate of erosion, while actual erosion rates from 2001 to 2003 are much

more dramatic. These damages would occur if the proposed project was not installed or the community did not relocate.

Residential Structure Assumptions

Several existing residences are within a 5 to 10 year range of the erosion line. It is assumed that as erosion approaches individual homes, homeowners will take steps to salvage their personal property. However, since there is limited available land in the community, it would be difficult to relocate buildings, so they are considered a total loss. It is estimated that much of the community's residential structures would be lost in the next 10 to 15 years.

Commercial and Public Buildings Assumptions

According to the Alaska Department of Commerce, Community, and Economic Development, there are 16 active business licenses in Shishmaref. These include city offices, the washeteria, arts and crafts stores, school, community center, and a variety of other public buildings. Under both erosion scenarios, these buildings will be lost within the 50 year planning horizon, with critical infrastructure being lost within 10 to 15 years.

Infrastructure Assumptions

Infrastructure includes power, communications, bulk fuel facilities, sewage lagoon, airport, and some water supply tanks. The airport and sewage lagoon have the greatest vulnerability. The power plant and bulk fuel facilities would likely be lost after the school.

5.6.2.4. Summary of Future Damages

The value of the combined land lost, residential and commercial buildings, public buildings and infrastructure lost, and the costs fuel tank decommissioning, and closure due to erosion at Shishmaref range from more than $47 million to more than $130 million for the 50-year project horizon.

5.6.3. What are potential costs associated with moving to a new location or an existing community?

Shishmaref has formed a Relocation Coalition consisting of city officials, Native village elders, and other community leaders that has identified an area on the western shores of Shishmaref Lagoon near Tin Creek where the community could relocate. Relocating Shishmaref and providing similar services currently afforded to Shishmaref residents would cost approximately $180 million.

A collocation of the community would be to Nome or Kotzebue. Nome has more room for a collocation and has a lesser cost of the two at $93 million.

5.6.4. What is the expected time line for a complete failure of the usable land?

The Shishmaref erosion rates are subject to many factors including weather, when sea ice is formed, amount of permafrost exposed, types of bank protection, and quantities of bank protection installed. Estimating future erosion for Shishmaref was done utilizing two erosion

rates. The current profile shows extreme rates of erosion that would all but eliminate the community's viability in about 10 years. The longer period record shows a slower rate of about 25 years until the community is no longer viable. Loss of viability in this example means a significant decrease in the ability of the community to provide basic services for its residents (e.g. power, water, education). These rates are highly subjective and can accelerate or decelerate based upon types of bank protection, magnitude and frequency of storms, and differences in soil conditions. Choosing a reasonable midpoint range yields a 10 to 15-year timeline before enough of the critical infrastructure is lost to force an evacuation.

Table 8 - Summarized Information for Shishmaref

Community	Costs of Future Erosion Protection	Cost to Relocate	How Long Does The Community Have*
Shishmaref	$ 16,000,000	$100 – 200 Million	10 -15 years

*These numbers assume no future erosion protection, including that listed here, is not implemented

5.7. Unalakleet

5.7.1. Community Information

Unalakleet is on Norton Sound at the mouth of the Unalakleet River, 148 miles southeast of Nome and 395 miles northwest of Anchorage. The community is at approximately 63° North Latitude and -160° (West) Longitude, (Sec. 03, T019S, R011W, Kateel River Meridian). Unalakleet is in the Cape Nome Recording District. The area encompasses 2.9 square miles of land and 2.3 square miles of water. Unalakleet has a subarctic climate with considerable maritime influences when Norton Sound is ice-free, usually from May to October. Winters are cold and dry. Average summer temperatures range from 47 to 62 degrees Fahrenheit; winter temperatures average -4 to 11 degrees Fahrenheit. Extremes have been measured from -50 to 87 degrees Fahrenheit. Precipitation averages 14 inches annually, with 41 inches of snow.

The Unalakleet shoreline.

Typical rock filled gabion bank protection

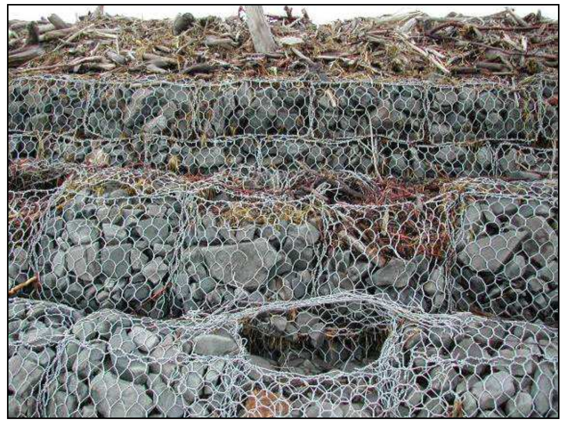
5.7.2. What are the costs associated with continued erosion?

Three elements associated with erosion costs are: past protection endeavors, the cost of ongoing repair and maintenance, and future damages. These are discussed in more detail in the following paragraphs.

5.7.2.1. Historical Erosion Protection Costs

In 2000 the Natural Resource Conservation Service (NRCS) constructed 1,400 feet of gabions (wire baskets filled with rock) beginning at the upstream end of the fish processing plant on the Unalakleet River and extending around the end of the spit approximately 1,000 feet with a cost of about $1.3 million. A late November storm in 2003 caused severe damage to the gabions. The State of Alaska signed a disaster declaration for this area and the community is applying for funding to repair the gabions. The estimated remaining life of the gabions ranges between 2 and 10 years. Failure would cause site specific damage to structures and facilities, but complete loss of the community is not expected.

Sagging Gabion Wall



Typical Gabion Cell Rupture

Erosion control efforts by the state from 1983 to 2004 totaled almost $2 million.

5.7.2.2. Cost of New Shoreline Protection

The existing bank protection at Unalakleet is in need of major repair or replacement. The gabion structure has been ruptured in places, spilling the rock core out where it can easily be washed away even during good weather conditions. The Corps is developing a project to remedy the erosion in this location through the construction of a riprap revetment with an estimated cost of about $30,000,000.

5.7.2.3. Future Damages

Residential Structures Assumptions

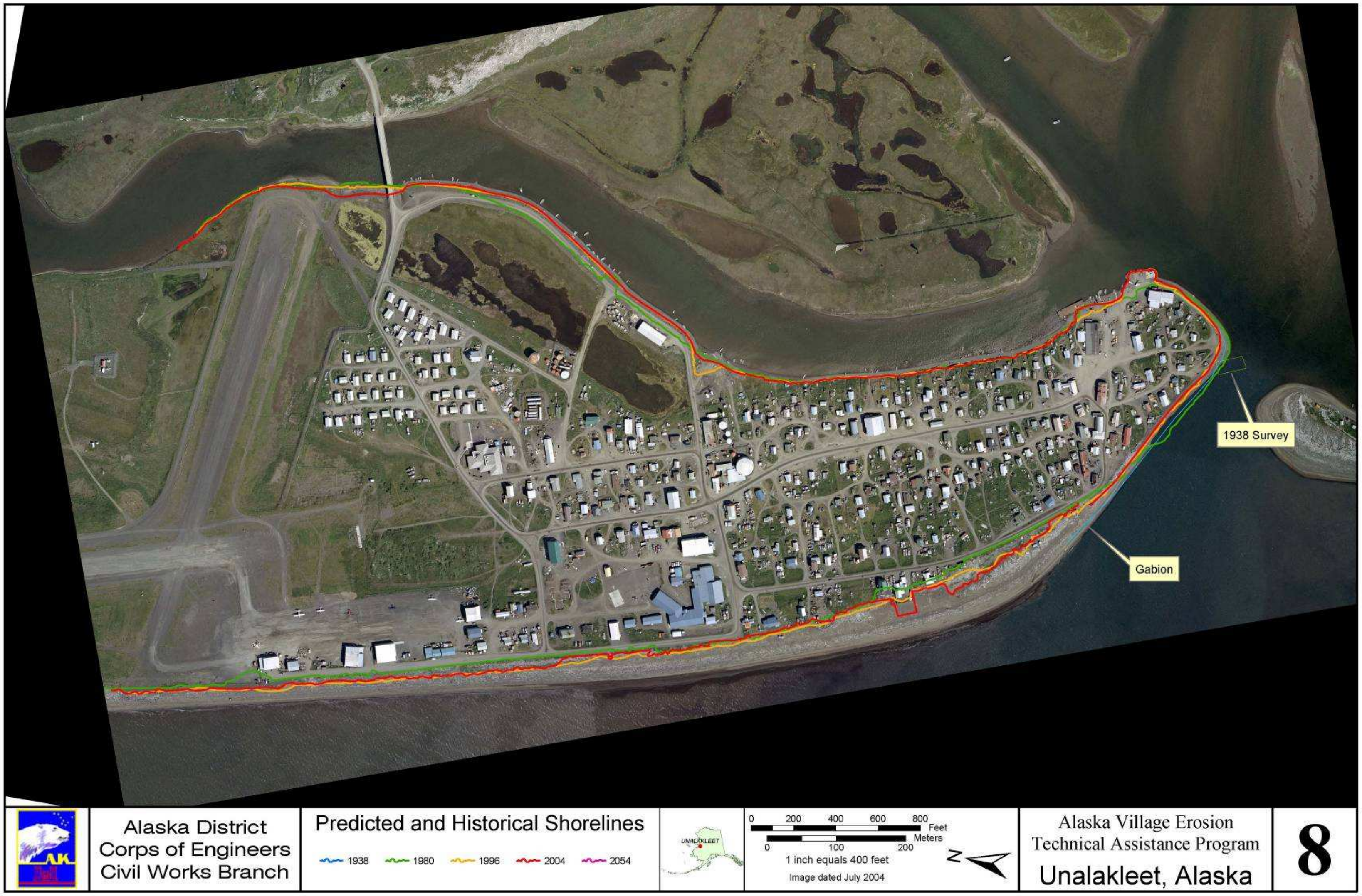
Some housing is be expected to be lost if the bank protection is not be repaired or replaced. These losses would be limited in nature to areas directly adjacent to gabion wall failure.

Commercial and Public Buildings Assumptions

The Unalakleet Fisheries processing plant is subject to erosion loss within the 50-year planning horizon. Due to the specialized nature of fish processing and the generally large pieces of equipment, it is assumed that moving the building and equipment out of harm's way is not an option.

Infrastructure Assumptions

Various site specific roads, electric and telephone lines, and water and sewer lines in the community are subject to loss, though the infrastructure as a whole is not be expected to be destroyed.


1938 Survey
Gabion
Alaska District
Corps of Engineers
Civil Works Branch
Predicted and Historical Shorelines
1938
1980
1996
2004
2054
UNALAKLEET
0 200 400 600 800 Feet
0 100 200 Meters
1 inch equals 400 feet
Image dated July 2004
N
Alaska Village Erosion
Technical Assistance Program
Unalakleet, Alaska
8

5.7.2.4. Summary of Future Damages

The combined residential, commercial and public buildings, and infrastructure costs due to erosion are more than $105 million for the 50-year project horizon if the existing protection is not repaired or no further erosion protection is installed.

5.7.3. What are potential costs associated with moving to a new location or an existing community?

There is no reasonable need for Unalakleet to relocate. With the exception of a few small segments, the erosion at Unalakleet has been contained. The rest of the erosion is currently being addressed though other means. In addition, the community and state have not expressed interest in relocating Unalakleet; therefore, costs for relocation were not developed.

5.7.4. What is the expected time line for a complete failure of the usable land?

Catastrophic failure of the sand spit is not expected; however, the community will continue to suffer property damage and loss from erosion. Unalakleet suffers from erosion on both the ocean side (Norton Sound) and from the Unalakleet River. The erosion rate on the Norton Sound side averages 1 foot per year and occurs when storm surge attacks the spit, washing away beach material. The rate of erosion from the Unalakleet River is more severe and averages 2 feet per year.

At current erosion rates the fish processing plant and some residences at the mouth of the Unalakleet River could be lost within 2 to 10 years. The community's water line running along Norton Sound could also be lost, as well as some parts of the airport. Over time, erosion will continue to capture some residences, roads, and utilities but the community as a whole will not be destroyed.

Table 9 - Summarized Information for Unalakleet

Community	Costs of Future Erosion Protection	Cost to Relocate	How Long Does The Community Have*
Unalakleet	$ 30,000,000	N/A	> 100 Years

*These numbers assume no future erosion protection, including that listed here, is not implemented

5.8. Summation of Community Information

It is very clear that there are many issues that need both immediate and continued attention. In addition, there is no clear cut way to rank communities in terms of need. The concern of ranking raises several questions. Is it best to use criteria that aids the most people, avoids the most damages, or has the earliest time horizon for failure? How do financial considerations (at the local, state, and national level) play into ranking the communities? If funds are limited and insufficient to help the community with the greatest need, would it be better to aid two other communities with smaller protection requirements? Would other social, environmental, or regional effects change our thinking in terms of the community with the greatest need?

Many other communities in the state also have erosion problems. This report examines only seven. The following tables summarize the information provided in this report for decision-makers and planners concerning these seven communities and erosion protection needs.

Table 10 – Summarized Community Information

Community	Costs of Future Erosion Protection	Cost to Relocate	How Long Does The Community Have*
Bethel	$ 5,000,000	N/A	> 100 years
Dillingham	10,000,000	N/A	> 100 years
Kaktovik	40,000,000	$ 20 – 40 Million	> 100 years
Kivalina	15,000,000	$ 80 – 120 Million	10 – 15 years
Newtok	90,000,000	$ 80 – 130 Million	10 – 15 years
Shishmaref	16,000,000	$100 – 200 Million	10 – 15 years
Unalakleet	30,000,000	N/A	> 100 years

*These numbers assume no future erosion protection, including that listed here, is not implemented.

6.0 ONGOING CORPS EFFORTS

Additional planning work and funding were identified in the Consolidated Appropriations Act of 2005, PL 108-447, Division C - Energy and Water Development Appropriations Act, 2005.

> *"Tribal Partnership Program.—The conferees acknowledge the serious impacts of coastal erosion and flooding due to continued climate change in Alaska. The conference expects the Corps to continue its work in this area and has included a total of $4,000,000, of which $2,000,000 is to combat erosion in Alaska. A field hearing was held in Anchorage, Alaska, on June 29 and 30, 2004, on the impacts of severe erosion and flooding on Alaska Native villages. There is no Federal or State agency to coordinate and assist these communities in the relocation or in the interim provide preventative measures to slow the effects of the erosion and flooding. The conference finds there is a need for an Alaska erosion baseline study to coordinate and plan the appropriate responses and assistance for Alaska villages in the most need and to provide an overall assessment on the*

priority of which villages should receive assistance. Therefore, the conference has provided the $2,000,000 for this study."

This legislation was implemented to provide additional funding through the Tribal Partnership program for technical activities for the seven named communities. Work continued in Kaktovik, Kivalina, Newtok, and Shishmaref to assist with studies and technical reports addressing various aspects of the erosion issue. No work was continued in Bethel, Dillingham, or Unalakleet because their activities were funded through other appropriations. The Alaska Baseline Erosion Assessment was initiated to identify, plan, and prioritize appropriate responses to ongoing erosion issues in Alaska communities.

In addition to more study authority and funding, in 2005 and 2006 a new authority was added for construction of projects at full Federal expense: Consolidated Appropriations Act of 2005, PL 108-447, Division C - Energy and Water Development Appropriations Act, 2005, which states as follows:

"SEC. 117. Notwithstanding any other provision of law, the Secretary of the Army is authorized to carry out, at full Federal expense, structural and non-structural projects for storm damage prevention and reduction, coastal erosion, and ice and glacial damage in Alaska, including relocation of affected communities and construction of replacement facilities."

Energy and Water Appropriations Bill, 2006, Senate Report 109-84, Page 41 states:

"The Committee has provided $2,400,000 for Alaska Coastal Erosion. The following communities are eligible recipients of these funds: Kivalina, Newtok, Shishmaref, Koyukuk, Barrow, Kaktovik, Point Hope, Unalakleet, and Bethel. Section 117 of Public Law 108-447 will apply to this project."

With the limited amount of funds identified for construction activities, a decision was made to focus efforts upon constructing additional shoreline protection for Shishmaref.

The authority and Congressional funding provided under Section 117 has allowed the Corps to focus on implementation of much needed coastal erosion projects through efficient planning, expedited design, and creative contracting methods.

6.1. Bethel

Bethel appears to have sufficient protection in place to protect it from the majority of erosion damages. A project is ready for construction to protect the remaining sections of stream bank once the non Federal sponsor provides the necessary real estate.

This bank stabilization project was authorized under Public Law (P.L.) 99-190, Section 116, Stat. 1318. The project provides for the extension of the existing Bethel Bank Stabilization Project. The project's Congressional Direction Source is the Energy and Water Development Appropriations Act of 2001, as enacted by Section 1(a) (2) of P.L. 106-377, Conference Report 106-988, page 211, and the Water Resources Development Act of 1986, Section 601, P.L. 99-662. It authorizes and directs the Corps to extend the existing project an additional 1,200 linear feet upstream.

Bethel was named in the 2006 Energy and Water Appropriation as a recipient of Section 117 funding; a letter report will be prepared in 2006 that will assess implementing the project under Section 117 at full Federal expense.

6.2. Dillingham

Similar to Bethel, Dillingham appears to have sufficient protection from erosion with the distinct exception of areas adjacent to the Dillingham small boat harbor. A project is being developed to address this erosion issue that consists of a breakwater and revetments to provide protection to the Dillingham small boat harbor, the regional fuel depot, and other facilities.

6.3. Kaktovik

Although no structures are expected to be impacted by erosion, there are significant cultural resources sites that are being exposed by erosion and may potentially be lost. The local community has expressed a strong desire for analysis of the archeological site and a determination of its magnitude, significance, and options for the future. Because of this a study is underway using Fiscal Year (FY) 2005 funding to catalog the resources being impacted.

Kaktovik was named in the 2006 Energy and Water Appropriation as a recipient of Section 117 funding, a letter report will be prepared in 2006 to assess needs for a Section 117 project.

6.4. Kivalina

The Corps is continuing a community planning effort to identify a cost effective relocation site that would be acceptable to the Kivalina community and to refine the costs, design requirements, and timeline for relocation. This work will include the development of an Environmental Impact Statement EIS to document the environmental and cultural impacts of ongoing erosion and potential relocation. Kivalina currently requires assistance to address an ongoing erosion problem that was recently worsened by fall storms. Kivalina was named in the 2006 Energy and Water Appropriation as a recipient of Section 117 funding. A letter report will be prepared in 2006 to assess implementing an interim erosion protection project under Section 117, followed by plans and specifications for the proposed project.

6.5. Newtok

The Corps is continuing to assist the community with developing a plan for relocation by refining costs, design requirements, and a timeline for relocation. This work will include the development of an EIS to document the environmental and cultural impacts of the ongoing erosion and potential relocation. Newtok was named in the 2006 Energy and Water Appropriation as a recipient of Section 117 funding. A letter report will be prepared in 2006 to assess implementing a project under Section 117.

6.6. Shishmaref

The Corps is completing documentation that discusses the environmental, social, and cultural impacts related to a relocation or co-location. Shishmaref currently requires assistance to address an ongoing erosion problem that could destroy the community before it could relocate. Several other documents were prepared in support of the environmental document. A report, Preliminary Cost of Alternatives, was prepared to document the costs of the community staying on Sarichef Island, moving to a new location, or co-locating with Nome or Kotzebue. The report, "We're always going back and forth", Kigiqtaamiut Subsistence Land Use and Occupancy For the Community of Shishmaref, was prepared to document the importance of subsistence activities for the community of Shishmaref, and the report Co Location Cultural Impact Assessment, documented the various impacts the community of Shishmaref would have if it were to relocate to a hub community such as Nome or Kotzebue.

Shishmaref was named in the 2006 Energy and Water Appropriation as a recipient of Section 117 funding. A letter report will be prepared in 2006 to assess implementing an interim erosion protection project under Section 117, followed by preparation of plans and specifications, and award of a construction contract for the proposed project in the latter part of FY 2006.

6.7. Unalakleet

Unalakleet appears to have preliminarily addressed their erosion issues through the construction of a gabion revetment; however, more work will need to be done to provide more permanent protection. Unalakleet was named in the 2006 Energy and Water Appropriation as a recipient of Section 117 funding. A letter report will be prepared in 2006 to assess implementing a more permanent erosion protection project under Section 117, followed by preparation of plans and specifications for the proposed project.

6.8. Other Communities

In the FY 2006 Energy and Water Appropriations Bill, Point Hope, Koyukuk, and Barrow were identified as other communities eligible for funding under Section 117. Barrow has a feasibility study underway to address its ongoing beach erosion and coastal flooding problem. A letter report will be prepared in 2006 to assess implementing a project under Section 117. The Corps has investigated conditions at Point Hope and Koyukuk under different programs with various degrees of Federal interest being found. A letter report that will assess implementing projects under Section 117 will be prepared for each community in 2006.

6.9. Other Studies

As mentioned previously, FY 2005 funding identified the need for an Alaska Baseline Erosion Assessment. The assessment is being prepared by coordinating with other agencies, planning appropriate responses to erosion problems, and prioritizing communities that need some sort of response. In FY 2005 a list of villages was identified as needing some assessment of their erosion problem. In FY 2006 and 2007, the villages' erosions problems and needs will be assessed and the reports will be made available as they are completed. About 165 communities in the state were identified to have specific erosion problems. Approximately 60 communities will be able to be addressed with the current appropriation.

The Corps has also used Tribal Partnership funding to perform Coastal Hydraulic Modeling. The purpose of this effort was to develop frequency-of-occurrence relationships of storm generated water levels and currents for selected village locations ranging from the Aleutian Islands to the south near the Canadian border to the north and east. The development of the storm-induced water levels and currents was accomplished by performing Advanced Circulation (ADCIRC) numerical model simulations for the Alaska coast along the Bering, Chukchi, and Beaufort seas. This effort will allow for a better understanding of the frequency and magnitude of storms, thus leading to better planning and design in the project development process.

7.0 CONCLUSION

This report has documented the wide variety of efforts the U.S. Army Corps of Engineers has undertaken using Tribal Partnership funding to address the ongoing erosion problems in Alaska. As stated in this report, our analysis uncovered many issues related to erosion protection and community relocation. Through the planning effort of the Tribal Partnership program, the Corps is addressing these issues and exploring solutions for some of the most critical villages. With the ongoing efforts of the Baseline Erosion Assessment and other programs, the Corps is working a strategy for now and the future to address erosion in Alaska. Ongoing work at all levels of the organization is seeking ways to streamline the Corps processes and to expedite implementation of common sense projects. Through continued support at all levels of government, the Corps can and will help lead the way towards success.

This technical report has been prepared by the Alaska District, U.S. Army Corps of Engineers in coordination with and with the assistance of multiple agencies, villages, and stakeholders. It is hereby respectfully submitted for your information.

/s/

Timothy J. Gallagher
Colonel, Corps of Engineers
District Commander

EXHIBIT E (Part 1 of 2)

United States General Accounting Office

GAO

Report to Congressional Committees

December 2003

ALASKA NATIVE VILLAGES

Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance

GAO

Accountability ★ Integrity ★ Reliability

December 2003

GAO
Accountability•Integrity•Reliability

Highlights

Highlights of GAO-04-142, a report to the Senate and House Committees on Appropriations

ALASKA NATIVE VILLAGES

Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance

Why GAO Did This Study

Approximately 6,600 miles of Alaska's coastline and many of the low-lying areas along the state's rivers are subject to severe flooding and erosion. Most of Alaska's Native villages are located on the coast or on riverbanks. In addition to the many federal and Alaska state agencies that respond to flooding and erosion, Congress established the Denali Commission in 1998 to, among other things, provide economic development services and to meet infrastructure needs in rural Alaska communities.

Congress directed GAO to study Alaska Native villages affected by flooding and erosion and to 1) determine the extent to which these villages are affected, 2) identify federal and state flooding and erosion programs, 3) determine the current status of efforts to respond to flooding and erosion in nine villages, and 4) identify alternatives that Congress may wish to consider when providing assistance for flooding and erosion.

What GAO Recommends

GAO presents to Congress a matter for consideration that directs federal agencies and the Denali Commission to assess the feasibility of alternatives for responding to flooding and erosion. In addition, GAO recommends that the Denali Commission adopt a policy to guide future infrastructure investments in Alaska Native villages affected by flooding and erosion.

www.gao.gov/cgi-bin/getrpt?GAO-04-142.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Anu Mittal at (202) 512-3841 or mittala@gao.gov.

What GAO Found

Flooding and erosion affects 184 out of 213, or 86 percent, of Alaska Native villages to some extent. While many of the problems are long-standing, various studies indicate that coastal villages are becoming more susceptible to flooding and erosion due in part to rising temperatures.

The Corps of Engineers and the Natural Resources Conservation Service administer key programs for constructing flooding and erosion control projects. However, small and remote Alaska Native villages often fail to qualify for assistance under these programs—largely because of agency requirements that the expected costs of the project not exceed its benefits. Even villages that do meet the cost/benefit criteria may still not receive assistance if they cannot meet the cost-share requirement for the project.

Of the nine villages we were directed to review, four—Kivalina, Koyukuk, Newtok, and Shishmaref—are in imminent danger from flooding and erosion and are planning to relocate, while the remaining five are in various stages of responding to these problems. Costs for relocating are expected to be high. For example, the cost estimates for relocating Kivalina range from $100 million to over $400 million. Relocation is a daunting process that may take several years to accomplish. During that process, federal agencies must make wise investment decisions, yet GAO found instances where federal agencies invested in infrastructure at the villages' existing sites without knowledge of their plans to relocate.

GAO, federal and state officials, and village representatives identified some alternatives that could increase service delivery for Alaska Native villages, although many important factors must first be considered:

- Expand the role of the Denali Commission.
- Direct federal agencies to consider social and environmental factors in their cost/benefit analyses.
- Waive the federal cost-sharing requirement for these projects.
- Authorize the "bundling" of funds from various federal agencies.

Bluff Erosion at Shishmaref

Source: GAO.

Contents

Tables

Figures

Abbreviations

ANCSA	Alaska Native Claims Settlement Act
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GAO	General Accounting Office
NAHASDA	Native American Housing Assistance Self-Determination Act of 1996
NRCS	Natural Resources Conservation Service
WRDA	Water Resources Development Act

GAO
Accountability * Integrity * Reliability

United States General Accounting Office
Washington, D.C. 20548

December 12, 2003

The Honorable Ted Stevens
Chairman
The Honorable Robert C. Byrd
Ranking Minority Member
Committee on Appropriations
United States Senate

The Honorable C.W. Bill Young
Chairman
The Honorable David R. Obey
Ranking Minority Member
Committee on Appropriations
House of Representatives

Alaska's shoreline is subject to periodic, yet severe, erosion. During these episodes, over 100 feet of land can be lost in a single storm. The state also has thousands of miles of riverbanks that are prone to annual flooding during the spring thaw. These shorelines and riverbanks serve as home to over 200 Native villages whose inhabitants hunt and fish for subsistence. Coastal and river flooding and erosion cause millions of dollars of property damage in Alaska Native villages, damaging or destroying homes, public buildings, and airport runways. Because Alaska Native villages are often in remote areas not accessible by roads, village airport runways are lifelines for many villages, and any threat to the runways either from flooding or erosion may be a threat to the villages' survival. Flooding and erosion can also destroy meat drying racks and damage food cellars, threatening the winter food supply and the traditional subsistence lifestyle of Alaska Natives.

Since 1977, the state, and in some cases the federal government, has responded to more than 190 disaster emergencies in Alaska, many in response to these problems. Several federal and state agencies are directly or indirectly involved in providing assistance for flooding and erosion in Alaska. In addition, the Denali Commission, created by Congress in 1998, while not directly responsible for responding to flooding and erosion, is charged with addressing crucial needs of rural Alaska communities,

particularly isolated Alaska Native villages.[1] The commission is composed of a federal and a state cochair and representatives from local agencies, as well as Alaska Native, public, and private entities. For fiscal year 2003, the commission was provided with almost $99 million in federal funds to carry out its mission. The purpose of the commission is to (1) deliver the services of the federal government in the most cost-effective manner practicable; (2) provide job training and other economic development services in rural communities; and (3) promote rural development and provide infrastructure such as water, sewer, and communication systems.

The fiscal year 2003 Conference Report for the military construction appropriation bill directed GAO to study Alaska Native villages affected by flooding and erosion.[2] In response to this direction and subsequent discussions with your staff, we (1) determined the extent to which Alaska Native villages are affected by flooding and erosion; (2) identified federal and Alaska state programs that provide assistance for flooding and erosion and assessed the extent to which federal assistance has been provided to Alaska Native villages; (3) determined the status of efforts, including cost estimates, to respond to flooding and erosion in select villages seriously affected by flooding and erosion; and (4) identified alternatives that Congress may wish to consider when providing assistance for flooding and erosion of Alaska Native villages.

To address the objectives for this report, we reviewed federal and state flooding and erosion studies and project documents and interviewed federal and state agency officials and representatives from each of the nine villages. We also visited four of the nine villages. While the committee directed us to include at least six villages in our study—Barrow, Bethel, Kaktovik, Kivalina, Point Hope, and Unalakleet—we added three more—Koyukuk, Newtok, and Shishmaref—based on discussions with congressional staff and with federal and Alaska state officials familiar with flooding and erosion problems. Appendix I provides further details about the scope and methodology of our review.

Results in Brief

According to federal and state officials in Alaska, 184 out of 213, or 86.4 percent of Alaska Native villages experience some level of flooding and

[1]Pub. L. No. 105-277, tit. III, 112 Stat. 2681 (1998).

[2]H. R. Conf. Rep. No. 107-731, at 15 (2002).

erosion, but it is difficult to assess the severity of the problem because quantifiable data are not available for remote locations. Native villages on the coast or along rivers are subject to both annual and episodic flooding and erosion. Various studies and reports indicate that coastal villages in Alaska are becoming more susceptible to flooding and erosion in part because rising temperatures cause protective shore ice to form later in the year, leaving the villages vulnerable to fall storms. For example, the barrier island village of Shishmaref, which is less than 1,320 feet wide, lost 125 feet of beach to erosion during an October 1997 storm. In addition, villages in low-lying areas along riverbanks or in river deltas are susceptible to flooding and erosion caused by ice jams, snow and glacial melts, rising sea levels, and heavy rainfall. For many villages, ice jams that form in the Kuskokwim and Yukon Rivers during the spring ice breakup cause the most frequent and severe floods by creating a buildup of water behind the jam. The resulting accumulation of water can flood entire villages. While flooding and erosion affect most Alaska Native villages, federal and state officials noted that Alaska has significant data gaps because of a lack of monitoring equipment in remote locations. This lack of baseline data makes it difficult to assess the severity of the problem.

The Continuing Authorities Program, administered by the U.S. Army Corps of Engineers, and the Watershed Protection and Flood Prevention Program, administered by the Department of Agriculture's Natural Resources Conservation Service, are the principal federal programs that provide assistance for the prevention or control of flooding and erosion. However, small and remote Alaska Native villages often fail to qualify for assistance under these programs because they do not meet program criteria. For example, according to the Corps' guidelines for evaluating water resource projects, the Corps generally cannot undertake a project when the economic costs exceed the expected benefits. With few exceptions, Alaska Native villages' requests for assistance under this program are denied because the project costs usually outweigh expected benefits. Even villages that meet the Corps' cost/benefit criteria may still fail to qualify if they cannot meet cost-share requirements for the project. The Department of Agriculture's Natural Resources Conservation Service's Watershed Protection and Flood Prevention Program also requires a cost/benefit analysis similar to that of the Corps. As a result, few Alaska Native villages qualify for assistance under this program. However, the Natural Resources Conservation Service has other programs that have provided limited assistance to these villages—in part because these programs consider additional social and environmental factors in developing their cost/benefit analysis. Besides programs administered by the Corps of Engineers and the

Natural Resources Conservation Service, there are several other federal and state programs that offer limited assistance to Alaska Native villages in responding to flooding and erosion. For example, the Federal Aviation Administration can assist with rebuilding or repairing airstrips that are affected by flooding and erosion, and the Alaska Department of Community and Economic Development provides coordination and technical assistance to communities to help reduce losses and damage from flooding and erosion. However, these programs are generally not prevention programs, but are available to assist communities in preparing for or responding to the consequences of flooding and erosion.

Of the nine villages we were directed to review, four—Kivalina, Koyukuk, Newtok, and Shishmaref—are in imminent danger from flooding and erosion and are making plans to relocate; the remaining villages are taking other actions. Kivalina, Newtok, and Shishmaref are working with relevant federal agencies to determine the suitability of possible relocation sites, while Koyukuk is in the early stages of planning for relocation. Because of the high cost of materials and transportation in remote parts of Alaska, the cost of relocation for these villages is expected to be high. For example, the Corps estimates that the cost to relocate Kivalina, which has a population of about 385, could range from $100 million for design and construction of infrastructure, including a gravel pad, at one site and up to $400 million for just the cost of building a gravel pad at another site. Cost estimates for relocating the other three villages are not yet available. The five villages not planning to relocate—Barrow, Bethel, Kaktovik, Point Hope, and Unalakleet—are in various stages of responding to their flooding and erosion problems. For example, two of these villages, Kaktovik and Point Hope, are studying ways to prevent flooding of specific infrastructure, such as the airport runway. In addition, Bethel, a regional hub in southwest Alaska with a population of about 5,471, has a project under way to stop erosion of its riverbank. The project involves repairing an existing seawall and extending it 1,200 feet to protect the entrance to the village's small boat harbor, at an initial cost estimate of more than $4.7 million and average annual costs of $374,000.

During our review of the nine villages, we found instances where federal agencies invested in infrastructure projects without knowledge of the villages' plans to relocate. For example, the Denali Commission and the Department of Housing and Urban Development were unaware of Newtok's relocation plans when they decided to jointly fund a new health clinic in the village for $1.1 million (using fiscal year 2002 and 2003 funds). While we recognize that development and maintenance of critical

infrastructure, such as health clinics and runways, are necessary as villages find ways to respond to flooding and erosion, we question whether limited federal funds for these projects are being expended in the most effective and efficient manner. Had the agencies known of the village's relocation plans they could have explored other, potentially less costly, options for meeting the village's needs, until it is able to relocate. The Denali Commission has recognized this issue as a concern and is working on a policy to ensure that investments are made in a conscientious and sustainable manner for villages threatened by flooding and erosion. Successful implementation of such a policy will depend in part on its adoption by individual federal agencies that also fund infrastructure development in Alaska Native villages. We are recommending that the Denali Commission adopt a policy that will guide future infrastructure investments and project designs in villages affected by flooding and erosion.

The unique circumstances of Alaska Native villages and their inability to qualify for assistance under a variety of federal flooding and erosion programs may require special measures to ensure that they receive certain needed services. Federal and Alaska state officials and Alaska Native village representatives that we spoke with identified several alternatives that could help mitigate the barriers that villages face in obtaining federal services. The alternatives discussed below may be considered individually or in combination. However, adopting some of these alternatives will require consideration of a number of important factors including the potential to set a precedent for other communities and programs as well as resulting budgetary implications.

- Expand the role of the Denali Commission to include responsibility for managing a flooding and erosion assistance program, which it currently does not have.

- Direct the Corps and the Natural Resources Conservation Service to consider social and environmental factors in their cost benefit analyses for projects requested by Alaska Native villages.

- Waive the federal cost-sharing requirement for flooding and erosion programs for Alaska Native villages.

In addition, as a fourth alternative, GAO identified the bundling of funds from various agencies to address flooding and erosion problems in Alaska Native villages. While we did not determine the cost or the national policy

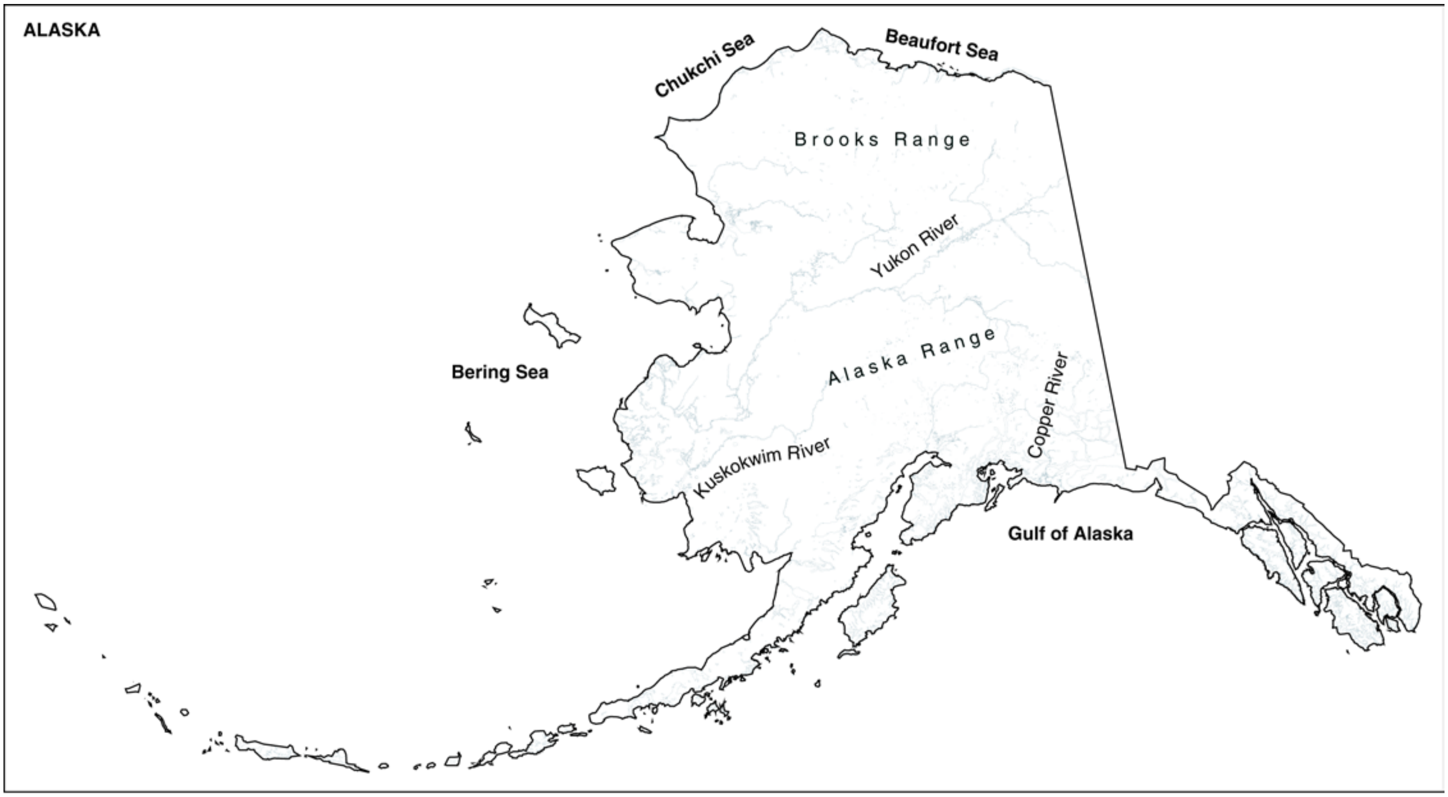
implications associated with any of these alternatives, these costs and implications are important considerations in determining the appropriate level of federal services that should be available to respond to flooding and erosion in Alaska Native villages. Consequently, we are providing Congress with a matter for consideration that it direct relevant executive agencies and the Denali Commission to assess the feasibility of each of the alternatives, as appropriate. In addition, the Denali Commission may want to comment on the implications of expanding its role.

Background

Alaska encompasses an area of about 365 million acres, more than the combined area of the next three largest states—Texas, California, and Montana. The state is bound on three sides by water, and its coastline, which stretches about 6,600 miles (excluding island shorelines, bays and fjords) and accounts for more than half of the entire U.S. coastline, varies from rocky shores, sandy beaches, and high cliffs to river deltas, mud flats, and barrier islands. The coastline constantly changes due to wave action, ocean currents, storms, and river deposits and is subject to periodic, yet severe, erosion. Alaska also has more than 12,000 rivers, including three of the ten largest in the country—the Yukon, Kuskokwim, and Copper Rivers.[3] (See fig. 1.) While these and other rivers provide food, transportation, and recreation for people, as well as habitat for fish and wildlife, their waters also shape the landscape. In particular, ice jams on rivers and flooding of riverbanks during spring breakup change the contour of valleys, wetlands, and human settlements.

[3]The size is determined by the average rate of flow (discharge at the mouth).

Figure 1: Map of Alaska Showing Major Rivers, Oceans, and Mountain Ranges



Source: Mapping information from Meridian GeoSystems, Inc.

Permafrost (permanently frozen subsoil) is found over approximately 80 percent of Alaska. It is deepest and most extensive on the Arctic Coastal Plain and decreases in depth, eventually becoming discontinuous further south. In northern Alaska, where the permafrost is virtually everywhere, most buildings are elevated to minimize the amount of heat transferred to the ground to avoid melting the permafrost. In northern barrier island communities, the permafrost literally helps hold the island together. However, rising temperatures in recent years have led to widespread thawing of the permafrost, causing serious damage. As permafrost melts, buildings and runways sink, bulk fuel tank areas are threatened, and slumping and erosion of land ensue. (See fig. 2.)

Figure 2: Sea Erosion at Shishmaref (June 2003)

Source: GAO.

Rising temperatures have also affected the thickness, extent, and duration of sea ice that forms along the western and northern coasts. The loss of sea ice leaves coasts more vulnerable to waves, storm surges, and erosion. When combined with the thawing of permafrost along the coast, this loss of sea ice poses a serious threat to coastal Alaska Native villages. Furthermore, loss of sea ice alters the habitat and accessibility of many of the marine mammals that Alaska Natives depend upon for subsistence. As the ice melts or moves away early, walruses, seals, and polar bears move with it, taking them too far away to be hunted.

Although Alaska is by far the largest state, it is one of the least populated, with about 630,000 people—of which 19 percent, or about 120,000, are Alaska Natives.[4] Over half of the state's population is concentrated in the Kenai Peninsula, Anchorage, and the Matanuska-Susitna area in south central Alaska. Many Alaska Natives, however, live in places long inhabited by their ancestors in rural areas in western, northern, and interior Alaska. Alaskan Natives are generally divided into six major groupings: Unangan (Aleuts), Alutiiq (Pacific Eskimos), Iñupiat (Northern Eskimos), Yup'ik (Bering Sea Eskimos), Athabascan (Interior Indians), and Tlingit and Haida (Southeast Coastal Indians).[5] For generations, these Alaska Natives have used the surrounding waters and land to hunt, fish, and gather wild plants for food. (See fig. 3.) These subsistence activities are intricately woven into the fabric of their lives. Subsistence activities require a complex network of social relationships within the Native community. For example, there is a division of labor among those who harvest, those who prepare, and those who distribute the food. These activities establish and promote the basic values of Alaska Native culture—generosity, respect for the knowledge and guidance of elders, self-esteem for the successful hunter(s), and community cooperation—and they form the foundation for continuity between generations. As their environment changes along with the climate, however, Alaska Natives have few adaptive strategies, and their traditional way of life is becoming increasingly vulnerable.

[4]The U.S. Census Bureau defines this category as American Indian and Alaska Native.

[5]Other Alaska Native groups include Siberian Yupik of St. Lawrence Island and Tsimshian of southeast Alaska.

Figure 3: Subsistence Harvesting of a Seal in Kivalina (June 2003)

Source: GAO.

A typical coastal or river Native village has a population of a couple of hundred people and generally contains only basic infrastructure—homes, a school, a village store, a health clinic, a washateria, a church, city or tribal offices, and a post office. The school is usually the largest building in the community. Since many villages do not have running water, the washateria plays an important role; it not only contains laundry facilities, but also shower and toilet facilities—which residents must pay a fee to use. Many village homes do not have sanitation facilities and rely on honey buckets—5-gallon buckets that serve as a toilet—or a flush and haul system.[6] Most of the villages that are not accessible by roads contain an airport runway that provides the only year-round access to the community. The runways are generally adjacent to the village or a short distance away. Other infrastructure in a village may consist of a bulk fuel tank farm, a power plant, a water treatment facility, a water tank, meat drying racks, a village

[6] A flush and haul system generally consists of individual storage tanks that provide water to flush toilets, and the sewage is then stored in a separate tank whose contents are transported to a sewage lagoon.

sewage lagoon or dump site, and, for some villages, commercial structures such as tanneries. Most river villages also have a barge landing area where goods are delivered to the community during the ice-free period.

Multiple Entities Make Up the Alaska Native Village Governing Structure

The government structure of Native villages may contain several distinct entities that perform administrative tasks, including making decisions about how to address flooding and erosion. Alaska's constitution and state laws allow for several types of regional and local government units, such as boroughs—units of government that are similar to the counties found in many other states. About a third of Alaska is made up of 16 organized boroughs. The remaining two-thirds of the state is sparsely populated land that is considered a single "unorganized borough." At the village level, a federally recognized tribal government may coexist with a city government, which may also be under a borough government. Alaska has more than 200 federally recognized tribal governments.

In addition to these various government entities, federal agencies that provide assistance for flooding and erosion also work with local and regional Native corporations. Federal law directed the establishment of these corporations under the laws of the state of Alaska, and the corporations are organized as for-profit entities that also have nonprofit arms. In December 1971, Congress enacted the Alaska Native Claims Settlement Act (ANCSA), which directed the establishment of 12 for-profit regional corporations—one for each geographic region comprised of Natives having a common heritage and sharing common interests—and over 200 village corporations.[7] These corporations would become the vehicle for distributing land and monetary benefits to Alaska Natives to provide a fair and just settlement of aboriginal land claims in Alaska. The act permitted the conveyance of about 44 million acres of land to Alaska Native corporations, along with cash payments of almost $1 billion.[8] (See appendix II for a list of the regional corporations and the corresponding nonprofit arms that provide social services to the villages and also help them address problems, including flooding and erosion.)

[7]Pub. L. No. 92-203, 85 Stat. 688 (1971). In addition, a thirteenth corporation was established later for nonresident Alaska Natives.

[8]A thirteenth regional corporation was later established for nonresident Alaska Natives. This corporation participated only in ANCSA's cash settlement and did not receive any ANCSA lands or other ANCSA benefits.

Several Federal and State Agencies Are Responsible for Responding to Flooding and Erosion

Federal, state, and local government agencies share responsibility for controlling and responding to flooding and erosion. The U.S. Army Corps of Engineers has responsibility for planning and constructing streambank and shoreline erosion protection and flood control structures under a specific set of requirements.[9] The Department of Agriculture's Natural Resources Conservation Service (NRCS) is responsible for protecting small watersheds. A number of other federal agencies, such as the Departments of Transportation and Housing and Urban Development, also have responsibility for protecting certain infrastructure from flooding and erosion. On the state side, the Division of Emergency Services responds to state disaster declarations dealing with flooding and erosion when local communities request assistance. The Alaska Department of Community and Economic Development helps communities reduce losses and damage from flooding and erosion. The Alaska Department of Transportation and Public Facilities funds work to protect runways from erosion. Local governments such as the North Slope Borough have also funded erosion control and flood protection projects.

In addition to government agencies, the Denali Commission, created by Congress in 1998, while not directly responsible for responding to flooding and erosion, is charged with addressing crucial needs of rural Alaska communities, particularly isolated Alaska Native villages. The membership of the commission consists of federal and state cochairs and a five-member panel from statewide organization presidents. The mission of the commission is to partner with tribal, federal, state, and local governments to improve the effectiveness and efficiency of government services; to build and ensure the operation and maintenance of Alaska's basic infrastructure; and to develop a well-trained labor force. The commission funds infrastructure projects throughout the state, ranging from health clinics to bulk fuel tanks. The commission has also funded the construction of new infrastructure when flooding and erosion threatened the existing structures.

[9] The Corps may study and construct erosion protection and flood control structures, provided it receives authority and appropriations from Congress to do so. In addition to building structures, the Corps may also consider and implement non-structural and relocation alternatives.

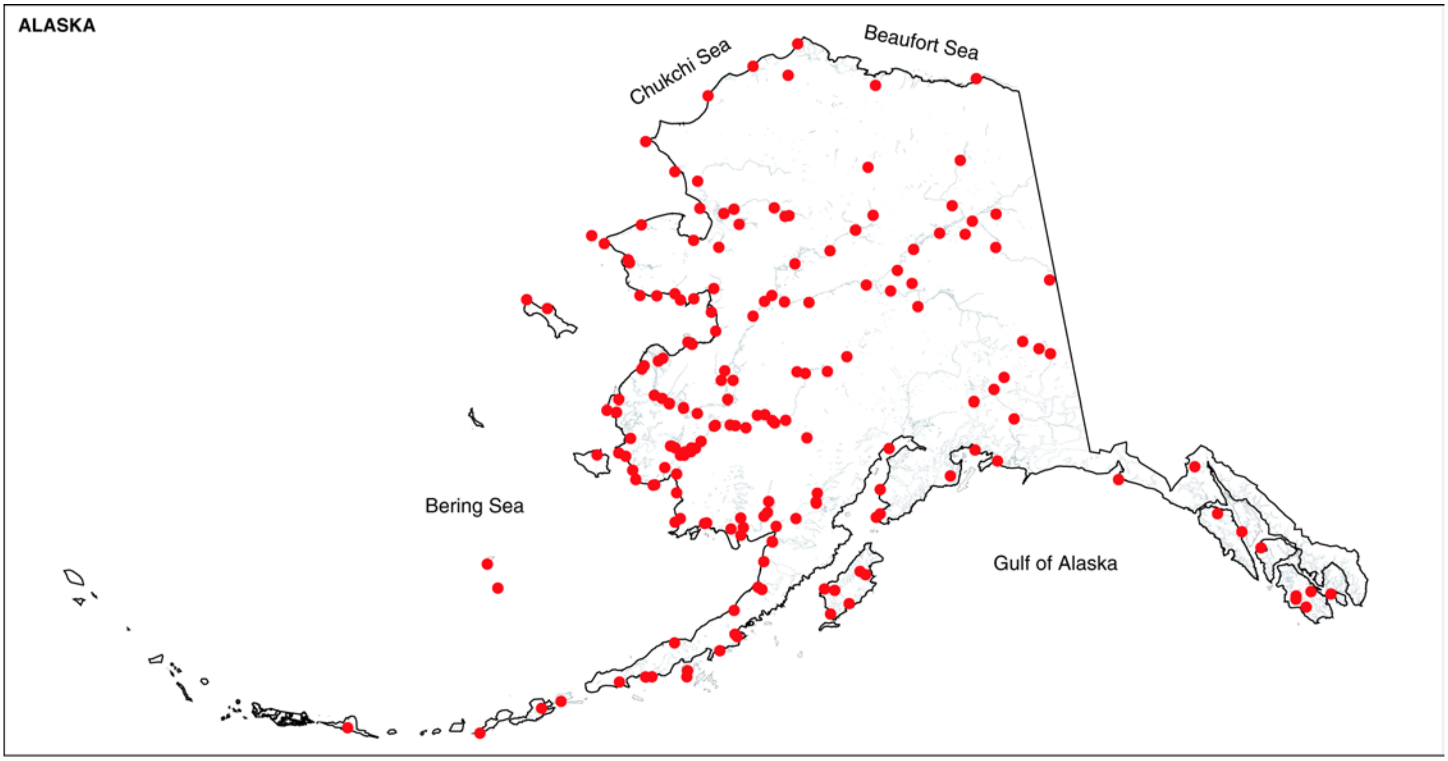
Most Alaska Native Villages Are Affected to Some Extent by Flooding and Erosion

According to federal and Alaska state officials that we consulted, most of the 213 Alaska Native villages are subject to flooding and erosion. However, it is difficult to assess the severity of the problem because quantifiable data on flooding and erosion are not available for remote locations. Villages located on the coast or along rivers are subject to both annual and episodic flooding and erosion. In addition, river villages are also susceptible to flooding and erosion caused by ice jams, snow and glacial melts, rising sea levels, and heavy rainfall.

Coastal or River Flooding and Erosion Affects 86 Percent of Alaska Native Villages

Flooding and erosion affects 184 out of 213, or 86.4 percent, of Alaska Native villages to some extent, according to studies and information provided to us by federal and Alaska state officials. The 184 affected villages consist of coastal and river villages throughout the state. Figure 4 shows the location of these villages, and table 1 shows the number of affected villages by ANCSA region. All 184 Native villages affected by flooding and erosion are listed in appendix III.

Figure 4: Locations of 184 Native Villages Affected by Flooding and Erosion



Sources: GAO (analysis); Meridian GeoSystems, Inc., (map).

Table 1: Number of ANCSA-Eligible Villages Affected by Flooding and Erosion, by Region

Region	Alaska Native villages	Alaska Native villages affected by flooding and erosion
Ahtna	8	4
Aleut	13	13
Arctic Slope	8	6
Bering Straits	20	18
Bristol Bay	29	27
Calista	56	49
Chugach	5	4
Cook Inlet Region	7	3
Doyon	37	33
Koniag	9[a]	6
NANA	11	11
Sealaska	10	10
Total	**213**	**184**

Source: GAO.

[a]There are seven additional ANCSA-eligible villages in the Koniag region, but they do not have corresponding Alaska Native entities recognized by the Department of the Interior's Bureau of Indian Affairs.

Villages on the coast are affected by flooding and erosion from the sea. For example, when these villages are not protected by sea ice, they are at risk of flooding and erosion from storm surges. Lack of sea ice also increases the distance over water, which can generate increased waves and storm surges. In the case of Kivalina, the community has experienced erosion from sea storms, particularly in late summer or fall. These storms can result in a sea level rise of 10 feet or more, and when combined with high tide, the storm surge becomes even greater and can be accompanied by waves that contain ice. In addition to coastal villages, communities in low-lying areas along riverbanks or in river deltas are susceptible to flooding and erosion caused by ice jams, snow and glacial melts, rising sea levels and heavy rainfall. For example, the village of Aniak, on the Kuskokwim River in southwestern Alaska, experiences flooding every 3 or 4 years. Ice jams that form on the river during the spring breakup cause the most frequent and severe floods in Aniak, sometimes accompanied by streambank erosion from the ice flow. (See fig. 5.)

Figure 5: Aerial View of Flooding in Aniak (c. 2002)

Source: Alaska Division of Emergency Services.

Flooding and erosion are long-standing problems in Alaska. For example, these problems have been well documented in Bethel, Unalakleet, and Shishmaref dating back to the 1930s, 1940s, and 1950s, respectively. The state has made several efforts to identify communities affected by flooding and erosion over the past 30 years. In 1982, a state contractor developed a list of Alaska communities affected by flooding and erosion.[10] This list identified 169 of the 213 Alaska Native villages, virtually the same villages identified by federal and state officials that we consulted in 2003. In addition, the state appointed an Erosion Control Task Force in 1983 to

[10]This report was prepared for the Alaska Department of Community and Regional Affairs, the predecessor of the Alaska Department of Community and Economic Development.

investigate and inventory potential erosion problems and to prioritize erosion sites by severity and need. In its January 1984 final report, the task force identified a total of 30 priority communities with erosion problems. Of these 30 communities, 28 are Alaska Native villages. Federal and state officials that we spoke with in 2003 also identified almost all of the Native communities in the 1984 report as villages needing assistance.

While flooding and erosion is a long-standing problem that has been documented in Alaska for decades, various studies and reports indicate that coastal villages in Alaska are becoming more susceptible. This increasing susceptibility is due in part to rising temperatures that cause protective shore ice to form later in the year, leaving the villages vulnerable to storms. According to the Alaska Climate Research Center, mean annual temperatures have risen for the period from 1971 to 2000, although changes varied from one climate zone to another and were dependent on the temperature station selected. For example, Barrow experienced an average temperature increase of 4.16 degrees Fahrenheit for the 30-year period from 1971 to 2000, while Bethel experienced an increase of 3.08 degrees Fahrenheit for the same time period.

Other studies have reported extensive melting of glaciers, thawing of permafrost, and reduction of sea ice that may also be contributing to the flooding and erosion problems of coastal villages in recent years. According to a 1999 report for the U.S. Global Change Research Program, glaciers in the arctic and subarctic regions have generally receded, with decreases in ice thickness of approximately 33 feet over the last 40 years. In addition, according to a 1997 report of the Intergovernmental Panel on Climate Change, much of the arctic permafrost is close to thawing, making it an area that is sensitive to small changes in temperature. The 1999 report for the U.S. Global Change Research Program also states that both the extent and thickness of sea ice in the arctic have decreased substantially in recent decades, with thickness decreasing by more than 4 feet (from 10-feet to 6-feet thick). The report also notes that loss of sea ice along Alaska's coast has increased both coastal erosion and vulnerability to storm surges. With less ice, storm surges have become more severe because larger open water areas can generate bigger waves.

Quantifiable Data Are Not Available to Fully Assess the Severity of the Problem

While most Alaska Native villages are affected to some extent by flooding and erosion, quantifiable data are not available to fully assess the severity of the problem. Federal and Alaska state agency officials could agree on which three or four villages experience the most flooding and erosion, but

they could not rank flooding and erosion in the remaining villages by high, medium, or low severity. These agency officials said that determining the extent to which villages have been affected by flooding and erosion is difficult because Alaska has significant data gaps. These gaps occur because remote locations lack monitoring equipment. The officials noted that about 400 to 500 gauging stations would have to be added in Alaska to attain the same level of gauging as in the Pacific Northwest.

In addition, the amount and accuracy of floodplain information in Alaska varies widely from place to place.[11] Detailed floodplain studies have been completed for many of the larger communities and for the more populated areas along some rivers. For example, the Federal Emergency Management Agency (FEMA) has published Flood Insurance Rate Maps that show floodplain boundaries and flood elevations for communities that participate in the National Flood Insurance Program. However, because only a handful of Alaska Native villages participate in the program, many of the villages have not had their 100-year floodplain identified by FEMA. In addition, little or no documented floodplain information exists for most of the smaller communities. Moreover, no consolidated record has been maintained of significant floods in Alaska Native villages. The Corps' Flood Plain Management Services has an ongoing program to identify the 100-year flood elevation, or the flood of record of flood-prone communities through data research and field investigations.

State of Alaska officials also noted that there is a lack of standards and terms for measuring erosion. Erosion zone guidance and federal (or state) standards by which to judge erosion risks are needed. They noted that while national standards for designing, developing and siting for the "100-year flood" event exists and are quantifiable and measurable, a similar standard for erosion, such as a distance measurement needs to be established.

[11] Floodplain refers to the lowlands adjoining the channel of a river, stream, or watercourse, or ocean, lake, or other body of standing water, which have been or may be inundated by floodwater. The channel of a stream or watercourse is part of the floodplain.

Federal Flooding and Erosion Programs Provide Limited Assistance to Alaska Native Villages; Some State Programs Are Also Available

The key programs that construct projects to prevent and control flooding and erosion are administered by the Corps and NRCS. However, Alaska Native villages have difficulty qualifying for assistance under some of these programs—largely because of program requirements that the economic costs of the project not exceed its economic benefits. In addition to the Corps and NRCS, several other federal and state agencies have programs to provide assistance for specific consequences of flooding and erosion, such as programs to replace homes or to rebuild or repair roads and airstrips.

Federal Programs Are Available to Respond to Problems Associated with Flooding and Erosion

The Continuing Authorities Program, administered by the Corps, and the Watershed Protection and Flood Prevention Program, administered by NRCS, are the principal programs available to prevent flooding and control erosion. Table 2 below lists and describes the five authorities under the Corps' Continuing Authorities Program that address flooding and erosion, while table 3 identifies the main NRCS programs that provide assistance for flooding and erosion.

Table 2: Authorities that Address Flooding and Erosion under the Corps' Continuing Authorities Program

Program authority	Description
Section 14 of the Flood Control Act of 1946	For emergency streambank and shoreline erosion protection for public facilities
Section 205 of the Flood Control Act of 1948	Authorizes flood control projects
Section 208 of the Flood Control Act of 1954	Authorizes flood control activities
Section 103 of the River and Harbor Act of 1962	Protect shores of publicly owned property from hurricane and storm damage
Section 111 of the River and Harbor Act of 1968	Mitigate shoreline erosion damage cause by federal navigation projects

Source: GAO analysis of Corps program information.

In addition to the Corps' Continuing Authorities Program, other Corps authorities that may address problems related to flooding and erosion include the following:

- Section 22 of the Water Resources Development Act of 1974, which provides authority for the Corps to assist states in the preparation of comprehensive plans for the development, utilization, and conservation of water and related resources of drainage basins.

- Section 206 of the Flood Control Act of 1960, which allows the Corps' Flood Plain Management Services' Program to provide states and local governments technical services and planning guidance that is needed to support effective flood plain management.

Table 3: NRCS Programs That Respond to Flooding and Erosion

Program	Description
Watershed Protection and Flood Prevention Program	Provides funding for projects that control erosion and prevent flooding. Limited to watersheds that are less than 250,000 acres.
Emergency Watershed Protection Program	Provides assistance where there is some imminent threat—usually from some sort of erosion caused by river flooding.
Conservation Technical Assistance Program	Provides technical assistance to communities and individuals to solve natural resource problems including reducing erosion, improving air and water quality, and maintaining or restoring wetlands and habitat.

Source: GAO analysis of NRCS program information.

In addition to these programs, several other federal programs can assist Alaska Native villages in responding to the consequences of flooding by funding tasks such as moving homes, repairing roads, or rebuilding airport runways. Table 4 lists these programs.

Table 4: Other Key Federal Programs That Can Address Problems Caused by Flooding and Erosion

Agency/program	Description
Federal Emergency Management Agency/National Flood Insurance Program	Makes flood insurance available to residents of communities that adopt and enforce minimum floodplain management requirements.
Federal Emergency Management Agency/Public Assistance Program	Provides supplemental federal disaster grant assistance for the repair, replacement, or restoration of disaster-damaged, publicly owned facilities and the facilities of certain nonprofit organizations.
Department of Transportation/Federal Highway Administration (FHWA)	Provides funding through the state of Alaska for roads, pedestrian facilities, and snowmobile trails. FHWA monies may be available to assist villages with improving or repairing roads/boardwalks.
Department of Transportation/Federal Aviation Administration (FAA)/Alaska Region Airports Division	Provides funding to improve airport infrastructure—including those threatened by flooding and erosion. Could fund relocation of an airport if necessitated by community relocation providing the airport meets criteria for funding—airport is in the National Plan of Integrated Airport System and meets FAA design standards. However, the villages first need to be relocated first before the new airport is built.
Housing and Urban Development/Community Development Block Grants Program	Provides grants to Indian tribes and Alaska Native villages to develop economic opportunities and build decent housing for low and moderate-income residents.
Housing and Urban Development/Native American Housing Assistance Self-Determination Act of 1996 (NAHASDA)	Provides grants and technical assistance to Indian tribes and Alaska Native villages to develop affordable housing for low-income families. NAHASDA funds could also be used to move homes that are threatened by flooding and erosion.
Housing and Urban Development/Imminent Threats Grants Program	Provides funding to alleviate or remove imminent threats to health or safety—including threats posed by flooding and erosion.
Bureau of Indian Affairs/Road Maintenance Program	Provides funding for maintaining and repairing roads, culverts, and airstrips in order to provide a foundation for economic development.
Bureau of Indian Affairs/Housing Improvement Program	Provides grants and technical assistance to replace substandard housing, including housing that is threatened, damaged, or lost due to erosion or flooding.
Department of Commerce's Economic Development Administration/Economic Adjustment Program	Provides assistance to protect and develop the economies of communities. This assistance could involve building erosion or flood control structures in order to protect village commercial structures, such as canneries.

Source: GAO analysis of agencies' data.

Villages Have Difficulty Qualifying for the Corps' Program

Small and remote Alaska villages often fail to qualify for assistance under the Corps' Continuing Authorities Program because they do not meet the program's criteria. In particular, according to the Corps' guidelines for evaluating water resource projects, the Corps generally cannot undertake a project whose costs exceed its expected benefits.[12] With few exceptions, Alaska Native villages' requests for the Corps' assistance are denied because of the Corps' determination that project costs outweigh the expected benefits. Alaska Native villages have difficulty meeting the cost/benefit requirement because many of these villages are not developed to the extent that the value of their infrastructure is high enough to equal the cost of a proposed erosion or flood control project. For example, the Alaska Native village of Kongiganak, with a population of about 360 people, experiences severe erosion from the Kongnignanohk River. The Corps decided not to fund an erosion project because the cost of the project exceeds the expected benefits and because many of the structures threatened are private property, which are not eligible for protection under a Section 14 Emergency Streambank Protection project. One additional factor that makes it difficult for Alaska Native villages to qualify for the Corps' program is that the cost of construction is high in remote villages—largely because labor, equipment, and materials have to be brought in from distant locations. The high cost of construction makes it even more difficult for villages to meet the Corps' cost/benefit requirements.

[12]The Corps' guidelines are based on the Flood Control Act of 1936, which provides that "the Federal Government should improve or participate in the improvement of navigable waters or their tributaries . . . if the benefits . . . are in excess of the estimated costs." 33 U.S.C. §701a.

Even villages that do meet the Corps' cost/benefit criteria may still fail to receive assistance if they cannot provide or find sufficient funding to meet the cost-share requirements for the project. By law, the Corps generally requires local communities to fund between 25 and 50 percent of project planning and construction costs for flood prevention and erosion control projects.[13] According to village leaders we spoke to, under these cost-share requirements they may need to pay hundreds of thousands of dollars or more to fund their portion of a project—funding that many of them do not have.[14]

Qualifying for Some NRCS Programs Is Less Difficult

As shown in table 3, NRCS has three key programs that can provide assistance to villages to protect against flooding and erosion—two of which are less difficult to qualify for than the Corps program. The NRCS programs are the Watershed Protection and Flood Prevention Program, the Emergency Watershed Protection Program, and the Conservation Technical Assistance Program. The purpose of the Watershed Protection and Flood Prevention Program is to assist federal, state, and local agencies and tribal governments in protecting and restoring watersheds from damage caused by erosion, and flooding.[15] Qualifying for funding under the NRCS Watershed Protection and Flood Prevention Program requires a cost/benefit analysis similar to that of the Corps. In fact, according to an NRCS headquarters official, there should be little if any difference in the standards for cost benefit analyses between the Corps and NRCS programs. As a result, few projects for Alaskan Native villages have been funded under this program.

[13]The Corps has the authority to make cost sharing adjustments based upon a community's ability to pay under section 103 (m) of the Water Resources Development Act of 1986, as amended. 33 U.S.C. §2213 (m).

[14]According to state of Alaska officials, historically the state has provided the nonfederal matching funds for most Corps of Engineers (and other federal projects), and with the extreme budget deficits currently faced by the state of Alaska, the matching funds have been severely limited.

[15]The Watershed Protection and Flood Prevention Program was authorized under the Watershed Protection and Flood Prevention Act, Pub. L. No. 83-566 (1954).

In contrast, some villages have been able to qualify for assistance from the Emergency Watershed Protection Program, because for this program NRCS's policy is different and allows consideration of additional factors in the cost/benefit analysis.[16] Specifically, NRCS considers social or environmental factors when calculating the potential benefits of a proposed project, and protecting the subsistence lifestyle of an Alaska Native village can be included as one of these factors. In addition, NRCS headquarters officials have instructed field staff to "take a second look" at proposed projects in which the potential benefits are nearly equal to the project costs. In some cases, according to NRCS's National Emergency Watershed Protection Program Leader, there may be unusual circumstances that might make the project worthwhile even if the costs slightly outweigh the benefits. One example provided by this official was for projects that involved protecting Native American burial grounds. Furthermore, while NRCS's program encourages cost sharing by local communities, this requirement can be waived when the local community cannot afford to pay. Such was the case in Unalakleet, where the community had petitioned federal and state agencies to fund its local cost-share of an erosion protection project and was not successful. Eventually, NRCS waived the cost-share requirement for the village and covered the total cost of the project itself. (See fig. 6.) Another NRCS official in Alaska estimated that about 25 villages have requested assistance under this program during the last 5 years; of these 25 villages, 6 received some assistance from NRCS, and 19 were turned down—mostly because there were either no feasible solutions or because the problems they wished to address were recurring ones. One factor that limits the assistance provided by the program is that it is intended for smaller scale projects than those that might be constructed by the Corps. Moreover, because this program is designed to respond quickly to emergencies, it is limited to addressing one-time events—such as repairing damage caused by a large storm—rather than addressing recurring flooding and erosion.

[16]The Emergency Watershed Protection Program was authorized under the Flood Control Act of 1950, Pub. L. No. 81-516 (1950).

Figure 6: NRCS Seawall Erosion Protection Project at Unalakleet (c. 2000)

Source: NRCS.

Unlike the other NRCS programs and the Corps program, NRCS's Conservation Technical Assistance Program does not require any cost benefit analysis to qualify for assistance.[17] An NRCS official in Alaska estimated that during the last 2 years, NRCS provided assistance to about 25 villages under this program. The program is designed to provide technical assistance to communities and individuals that request help to solve natural resource problems, improve the health of the watershed, reduce erosion, improve air and water quality, or maintain or improve wetlands and habitat. The technical assistance provided can range from

[17]The Conservation Technical Assistance Program was authorized under the Soil Conservation and Domestic Allotment Act of 1935, Pub. L. No. 74-46 (1935).

advice or consultation services to developing planning, design, and/or engineering documents. The program does not fund the construction or implementation of a project.

Alaska State Programs Are Also Available to Respond to Flooding and Erosion

In addition to the federal programs, the state of Alaska has programs to help address or respond to flooding and erosion problems of Alaska Native villages. These include:

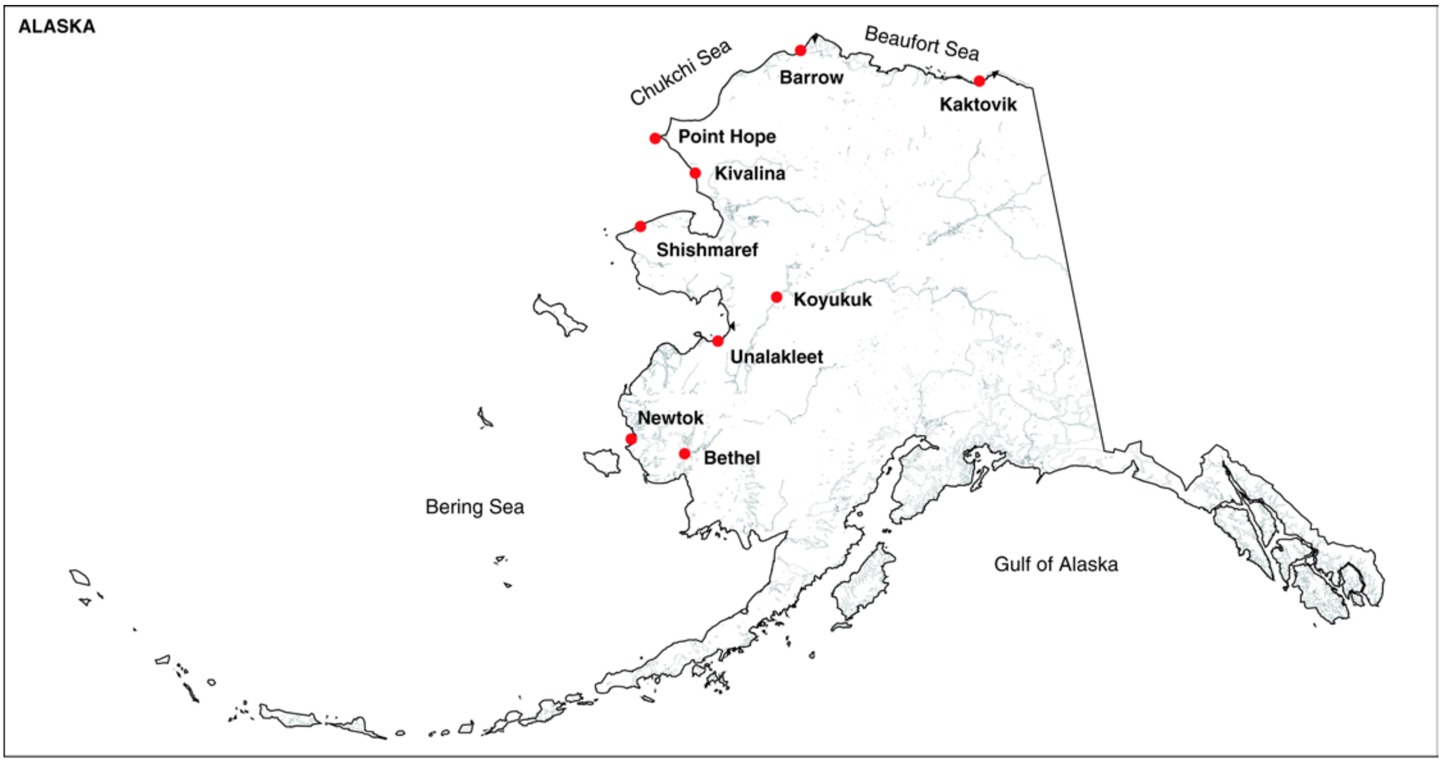
- The Alaska Department of Transportation and Public Facilities, which funds work through its maintenance appropriations to protect village airstrips from erosion.
- The Alaska Department of Community and Economic Development, which has a floodplain management program that provides coordination and technical assistance to communities to help reduce public-and private-sector losses and damage from flooding and erosion.
- The Alaska Department of Environmental Conservation, which has a Village Safe Water Program that can pay to relocate water or sewage treatment facilities that are threatened by erosion.
- The Alaska Housing Financing Corporation, which has a program to provide loans or grants to persons in imminent danger of losing their homes.
- The Alaska Division of Emergency Services, which coordinates the response to emergencies resulting from flooding and erosion, as requested by local communities. Its mission is to lead, coordinate, and support the emergency management system, in order to protect lives and prevent the loss of property from all types of hazards. With authorization from the governor, the state Disaster Relief Fund can make up to $1 million (without legislative approval) available to communities recovering from a state declared disaster. More funding may be available, with legislative approval, for presidential disaster declarations, for which the state is obligated to pay a 25 percent funding match.

In addition to these programs, the state legislature, through its appropriations, has funded erosion control structures including bulkheads and sea walls. According to state documents, between 1972 and 1991 the state spent over $40 million for erosion control statewide.

Four Villages in Imminent Danger Are Planning to Relocate, and the Remaining Five Villages Are Taking Other Actions

Four of the nine villages we reviewed are in imminent danger from flooding and erosion and are making plans to relocate, while the remaining five are taking other actions. (See fig. 7.) Of the four villages relocating, Kivalina, Newtok, and Shishmaref are working with relevant federal agencies to locate suitable new sites, while Koyukuk is just beginning the relocation planning process. The cost of relocating these villages is expected to be high, although estimates currently exist only for Kivalina. Of the five villages not planning to relocate, Barrow, Kaktovik, Point Hope, and Unalakleet each have studies under way that target specific infrastructure that is vulnerable to flooding and erosion. The fifth village, Bethel, is repairing and extending an existing seawall to protect the village's dock from river erosion. Table 5 summarizes the status of the nine villages' efforts to respond to their specific flooding and erosion problems. During our review of the nine villages, we found instances where federal agencies had invested in infrastructure projects without knowledge of the villages' plans to relocate.

Figure 7: Map of Alaska with Nine Villages Highlighted



Source: Mapping information from Meridian GeoSystems, Inc.

Table 5: Nine Alaska Native Villages' Efforts to Address Flooding and Erosion

Alaska Native village	Population	Status of efforts
Villages planning to relocate		
Kivalina	377	Located on a barrier island that is both overcrowded and shrinking. Cost estimates to relocate range from $100 million to over $400 million. The village is working with the Corps on further site selections for evaluation.
Shishmaref	562	Located on a barrier island and experiencing chronic erosion. Working on constructing a temporary seawall while concurrently working on a relocation site selection with NRCS.
Newtok	321	Suffers chronic erosion along its riverbank. Legislation for a land exchange with the U.S. Fish and Wildlife Service became law in November 2003 (Pub. L. No. 108-129). Under the Corps' Planning Assistance to States Program, the relocation study is continuing.
Koyukuk	101	Experiences severe flooding from Yukon and Koyukuk Rivers. Community is in the process of assessing prospective relocation sites.
Villages taking other actions		
Kaktovik	293	Airport runway is subject to annual flooding. FAA-funded study under way to determine least cost alternative.
Point Hope	757	Airport runway experiences flooding and is at risk of erosion. The North Slope Borough is analyzing construction alternatives for an evacuation road.
Barrow	4,581	The Corps has begun a feasibility study to address beach flooding and erosion problems, particularly along the village's utility corridor.
Unalakleet	747	Coastal and river flooding and erosion have combined to create a chronic problem at the harbor. The Corps has begun a study on improving navigational access.
Bethel	5,471	Spring break-up ice jams on the Kuskokwim River cause both periodic flooding and severe erosion along the riverbank. A seawall to protect the dock and small boat harbor is currently being repaired and extended.

Source: GAO analysis.

Four Villages in Imminent Danger Are Making Plans to Relocate

Four villages—Kivalina, Koyukuk, Newtok, and Shishmaref—are in imminent danger of flooding and eroding and are planning to relocate. (See table 5.) Kivalina and Shishmaref are located on barrier islands that are continuously shrinking due to chronic erosion. In Newtok, the Ninglick River is making its way ever closer to the village, with an average erosion rate of 90 feet per year, and is expected to erode the land under homes, schools, and businesses within 5 years. The fourth village, Koyukuk, is located near the confluence of the Yukon and Koyukuk Rivers and experiences chronic annual flooding.

Kivalina

The village of Kivalina lies on a barrier island that is both overcrowded and shrinking from chronic erosion. Surrounded by the Chukchi Sea and the

Kivalina Lagoon, the village has no further room for expansion. (See fig. 8.) A 1994 study by a private contractor found more than one instance of 16 people living together in a 900-square-foot home. Overcrowding and poor sanitation have led to an extremely high incidence of communicable diseases and other health problems in Kivalina. Chronic erosion on the lagoon side of the island and along its southeastern tip where the lagoon empties into the sea has further exacerbated overcrowding. Several homes along this side are currently in danger of falling into the lagoon. On the seaside of the island, fall storm surges create annual coastal flooding and beach erosion. Portions of the island have been breached before, and it is believed that the right combination of storm events could flood the entire village at any time.

Figure 8: Aerial view of Kivalina (c. 1999)

Source: FAA.

In 1990, the Corps placed sandbags around the southern tip of the island in an attempt to stem the erosion, but that proved to be only a temporary solution. Most recent efforts to respond to flooding and erosion have involved studying the feasibility of possible relocation sites. The villagers would like a site that is near their current location with access to the ocean so that they can continue to pursue their subsistence lifestyle. Much of the surrounding area, however, is low-lying wetlands or tundra. One of the main obstacles for selecting a site has been the requirement of a gravel pad for some of the sites under consideration. In those cases, several feet of gravel must be spread over the entire site, both to elevate the new village above the floodplain and to protect the fragile permafrost. However, gravel is not easily accessible and would have to be barged in. Similarly, the harsh, remote terrain and limited site access drive up other costs for materials and machinery. The Corps has estimated that the cost to relocate Kivalina could range from $100 million for design and construction of infrastructure (including a gravel pad) at one site and up to $400 million for just the cost of building a gravel pad at another site. As a result, the community is now considering whether to ask the Corps to evaluate completely new sites that would not require a gravel pad. Remaining on the island, however, is no longer a viable option for the community.

Shishmaref

Like Kivalina, the village of Shishmaref is located on a barrier island in the Chukchi Sea and experiences chronic erosion. During severe fall storms, as occurred in 1973, 1997, 2001, and 2002, the village has lost on average between 20 and 50 feet of land and up to 125 feet at one time. This loss is considerable for an island that is no wider than one-quarter mile (1,320 feet). After a severe storm in October 2002, stress cracks along the western seaside bluffs became evident. These cracks were 5 to 10 feet from the edge of the banks and indicated that the permafrost that holds the island together had been undermined by the storm. As the permafrost melts, the banks cave in. (See fig. 9.) Several homes located along these banks had to be relocated to prevent them from falling into the sea. After the 1997 fall storm, which was declared a state disaster, FEMA and state matching funds were used to help move 14 homes along the coastal bluff to another part of the village, and in 2002, the Bering Straits Housing Authority relocated an additional 5 homes out of harm's way.

Figure 9: Bluff Erosion and Permafrost Melting in Shishmaref (c. 2002)

Source: Kawerak.

Although the Corps had informed the villagers of Shishmaref in 1953 that relocation would be a cheaper alternative to building a seawall to protect the bluffs, the community did not vote to relocate until 1973 when it experienced two unusually severe fall storms that caused widespread damage and erosion. However, the site that the community selected proved to be unsuitable because it had an extensive layer of permafrost. Furthermore, other government agencies told the villagers that they would not receive funding for their new school or a much-needed new runway if they decided to relocate. According to Corps documents, the community reversed its decision and voted in August 1974 to stay on the island. The new school was completed in 1977, and a few years later a new runway was also built.

Since the 1970s, the village has attempted a variety of erosion protection measures totaling more than $5 million. These projects have included various sandbag and gabion seawalls (wire cages, or baskets, filled with

rocks) and even a concrete block mat. Each project has required numerous repairs and has ultimately failed to provide long-term protection. In October 2001, the governor of Alaska issued an administrative order for an $85,000 protective sandbag wall that was intended to last only one storm—and it did just that. In July 2002, the community again voted to relocate, and it is currently working with NRCS to select an appropriate site. Once a site is selected, the relocation process itself will take a number of years to complete. In the meantime, stopgap erosion protection measures and other federal and state services continue to be necessary to safeguard the community. For this reason, the community is working with Kawerak, a nonprofit Native corporation, to build a 500-foot seawall at an estimated cost of $1 million along the most affected part of the seaside bluff. The village is also seeking the Corps' assistance to extend the wall farther to protect the school and other public buildings. In addition, the community is applying for assistance through the Alaska Army National Guard's Innovative Readiness Training Program, in which guard units gain training and experience while providing medical, transportation, and engineering services to rural villages.

Newtok

The village of Newtok, located in the Yukon-Kuskokwim Delta on the Ninglick River, suffers from chronic erosion along its riverbank. Between 1954 and 2001 the village lost more than 4,000 feet of land to erosion. The current erosion rate has been estimated at 90 feet per year. At this rate, the Corps believes that the land under village residences and infrastructure will erode within 5 years.[18] Among its various attempts to combat erosion, the village placed an experimental $750,000 sandbag wall along the riverbank in 1987. The wall, however, failed to slow the rate of erosion. The community recently negotiated a land exchange with the U.S. Fish and Wildlife Service for a new village site. Legislation authorizing the conveyance to Newtok of both the surface and subsurface estate of specified federal lands on nearby Nelson Island in exchange for land the village currently owns or would receive title to under ANCSA was signed

[18]Under the Tribal Partnership Program, authorized by section 203 of the Water Resources Development Act of 2000 (Pub. L. No. 106-541, 114 Stat. 2572, 2588-2589 (2000)), the Corps is currently examining impacts of coastal erosion due to continued climate change and other factors in the Alaska Native villages of Bethel, Dillingham, Shishmaref, Kaktovik, Kivalina, Unalakleet and Newtok. Congress provided $2 million for these activities in fiscal year 2003.

into law in November 2003.[19] In anticipation of a move, the village is studying the soils and geology of the proposed relocation site to determine its suitability.

Koyukuk

The fourth village planning to relocate is Koyukuk, which is located entirely in a floodplain near the confluence of the Yukon and Koyukuk rivers. It experiences severe flooding, mostly as a result of ice jams that occur after the spring breakup of river ice. (See fig. 10.) Water that accumulates behind the ice jams repeatedly floods homes and public structures, including the school and runway. The flooding is episodic, but villagers prepare for it every year in the spring by placing their belongings in high places and putting their vehicles on floats. The village has been evacuated more than once. In July 2003, with funding assistance from FEMA, the Tanana Chiefs Conference, which is a nonprofit regional corporation, developed a flood mitigation plan for Koyukuk that includes both evacuation and relocation strategies. The community is in the process of assessing prospective relocation areas to find an appropriate site. In the meantime, the FAA has awarded a grant to the state to both raise the grade of and lengthen Koyukuk's runway at a cost of $10.3 million.[20]

[19] Pub. L. No. 108-129, 117 Stat. 1358 (2003).

[20] According to FAA officials, the planned relocation of the village will not include the construction of another airport.

Figure 10: Aerial View of Ice Jam and Flooding at Koyukuk, Near the Confluence of the Yukon and Koyukuk Rivers (c. 2001)

Source: Alaska Division of Emergency Services.

Five Villages Are Conducting Flooding and Erosion Studies or Improving Infrastructure

The remaining five villages, while not in imminent danger, do experience serious flooding and erosion and are undertaking various infrastructure-specific activities to resolve these problems. Kaktovik is studying how best to address flooding of its airport runway. Point Hope is studying alternatives for an emergency evacuation road in the event of flooding. Barrow has a study under way for dealing with beachfront erosion that threatens the village's utility corridor. Unalakleet is beginning a study to respond to erosion problems at its harbor and improve its navigational access. Finally, Bethel is repairing and extending an existing seawall to protect the village's dock from river erosion.

Kaktovik

The village of Kaktovik, located on Barter Island at the northern edge of the Arctic National Wildlife Refuge, experiences flooding of its airport runway. The eastern end of the runway is approximately 1 to 2 feet above mean sea level, while the western end is approximately 7 to 8 feet above mean sea level. As a result of this low elevation, the runway usually floods every fall and is inoperative for 2 to 4 days, according to Kaktovik's mayor. In 2000, the North Slope Borough, which operates the airport, contracted with the

Arctic Slope Consulting Group, Inc., to conduct a flood study at the airport. The study presented a preliminary cost estimate of $11.3 million for protecting the runway from damage by storm events resulting in 100-year flood conditions. Recently, the North Slope Borough and FAA hired an engineering company to prepare an Airport Master Plan that will provide alternatives for upgrading the existing runway or building a new airport, either on Barter Island (estimated at $15 to $20 million) or on the mainland (estimated at $25 to $35 million). FAA will support the least-cost alternative and will fund 93.75 percent of the project, while the North Slope Borough will fund the remaining 6.25 percent. The study should be completed in 2004.

Point Hope

The village of Point Hope, located on a spit of land that is one of the longest continually inhabited areas in northwest Alaska (with settlements over 2,500 years old), moved to its current location in the 1970s because of flooding and erosion problems at its original site. However, flooding and erosion remain a concern for the community at its new location, prompting efforts to build an evacuation road and relocate its runway. The North Slope Borough has funded a Project Analysis Report that assesses three construction options for an emergency evacuation road, which include reconstructing an existing road, extending that road to the mainland, or constructing a new road altogether. The road would not only facilitate emergency evacuation in the event of a flood, but would also provide a transportation route to a relocated runway. The village's current runway, which is a mile west of the current village and extends to the Chukchi Sea, floods during fall storms and is at risk of erosion. According to village representatives, the runway was inoperable for 5 days last year because of flooding. (See fig. 11.) One end of the runway is currently about 80 feet from the ocean, and village officials estimate that between 5 to 8 feet of land are lost to erosion annually. They noted however, that a single storm could take as much as 20 feet of land.

Figure 11: Airport Runway at the Native Village of Point Hope (c. 2001)

Source: Tikigaq Corporation.

Barrow

The Alaska Native village of Barrow is grappling with ways to address beach erosion and flooding. Much of the community's infrastructure is at risk from storm damage, shoreline erosion, and flooding. About $500 million of Barrow's infrastructure is located in the floodplain. In particular, the road that separates the sewage lagoon and an old landfill from the sea is at risk, as well as the village's utility corridor. This underground corridor contains sewage, water and power lines, and communication facilities for the community. Beach erosion threatens over 1 mile of the corridor. According to village and North Slope Borough officials, the Borough coordinates erosion projects for the village and spends about $500,000 each time there is a flood. The Corps has recently begun a feasibility study for a storm damage reduction project along Barrow's beach.

Unalakleet

The Alaska Native village of Unalakleet experiences both coastal and river flooding, which, when combined with shoreline erosion, have created an access problem at the harbor. Eroded land has piled up at the harbor mouth, creating six distinct sandbars. These sandbars pose a serious problem for barge passage; barges and fishing boats must wait for high tide to reach the harbor, delaying the delivery of bulk goods, fuel, and other items, which increases the costs of the cargo and moorage. The sandbars also pose a risk to those whose boats get stuck at low tide and who must simply sit and wait for a high tide. Unalakleet serves as a subregional hub for several nearby villages that rely on the harbor and fish processing plant for conducting their commercial fishing businesses. The village was recently able to raise $400,000 from the Norton Sound Economic Development Corporation and $400,000 from Alaska Department of Transportation and Public Facilities for the local share of a Corps study on improving navigational access to its harbor.

Bethel

Bethel, the regional village hub of the Yukon-Kuskokwim Delta, experiences periodic flooding, mostly because of ice jams during the spring breakup of the Kuskokwim River. The ice also causes severe erosion by scouring the riverbanks. The spring ice breakup in 1995 caused such severe erosion that the governor of Alaska declared a state of emergency—ice scour created a cove 350 feet long and 200 feet inland, endangering several structures and severely undercutting the city dock. The village's main port is the only one on the western Alaska coast for oceangoing ships and serves as the supply center for over 50 villages in the Yukon-Kuskokwim Delta. In response to the 1995 emergency, the village placed rock along 600 linear feet of the riverbank and dock. This was the beginning of an 8,000-foot bank stabilization seawall that cost $24 million. Currently, the Corps has a project under way to repair this seawall by placing more rock and by replacing the steel tieback system and placing steel wale on the inland side of the pipe piles. The project will also extend the seawall 1,200 feet so that it protects the entrance to Bethel's small boat harbor. The initial cost estimate for this project in 2001 was over $4.7 million, with average annual costs of $374,000.

Federal Agencies Are Investing in Infrastructure without Knowledge of Villages' Relocation Plans

During our review of these villages, we found instances where federal agencies invested in infrastructure projects without knowledge of the villages' plans to relocate. For example, the Denali Commission and the Department of Housing and Urban Development were unaware of Newtok's relocation plans when they decided to jointly fund a new health clinic in the village for $1.1 million (using fiscal year 2002 and 2003 funds).

During our site visit to Newtok, we observed that the new clinic's building materials had already been delivered to the dock. Once it is constructed and the village is ready to relocate, moving a building the size of the new clinic across the river may be difficult and costly. Neither the Denali Commission nor the Department of Housing and Urban Development realized that the plans for Newtok's relocation were moving forward, even though legislation for completing a land exchange deal with the U.S. Fish and Wildlife Service was first introduced in March 2002. Similarly, in Koyukuk, the FAA was initially unaware of the village's relocation plans when it solicited bids for a $10.3 million state project to increase the grade of and lengthen the village's existing runway, according to FAA officials. When we further discussed this with FAA officials, however, they noted that it is the state of Alaska that prioritizes and selects the transportation projects that receive FAA grants. According to these FAA officials, who awarded the grant for Koyukuk's runway, state transportation officials were aware of the village's decision to relocate.

Although we recognize that development and maintenance of critical infrastructure, such as health clinics and runways, are necessary as villages find ways to address flooding and erosion, we question whether limited federal funds for these projects are being expended in the most effective and efficient manner possible. The Denali Commission, cognizant of the stated purpose of its authorizing act to deliver services in a cost-effective manner, has developed a draft investment policy intended to guide the process of project selection and ensure prudent investment of federal funds. The draft policy provides guidance for designers to tailor facilities based on six primary investment indicators: size of community and population trends, imminent environmental threats, proximity/access to existing services and/or facilities, per capita investment benchmarks, unit construction costs, and economic potential. These indicators provide the Denali Commission and its partners with an investment framework that will guide selection and funding for sustainable projects. Flooding and erosion issues fall under the "imminent environmental threats" indicator. The commission has applied this draft policy to Shishmaref, which requested a new clinic at its current location. Given that the village is in the process of relocating, the commission awarded $150,000 to repair the existing clinic in Shishmaref in lieu of building a new clinic.

In addition, the Denali Commission recognizes that systematic planning and coordination on a local, regional, and statewide basis are necessary to achieve the most effective results from investments in infrastructure, economic development, and training, and has signed a memorandum of

understanding with 31 federal and state agencies to achieve this goal. This memorandum of understanding could serve as a vehicle by which other federal agencies would follow the lead of the Denali Commission regarding decisions to invest in infrastructure for communities threatened by flooding and erosion.

Alternatives for Addressing Barriers That Villages Face in Obtaining Federal Services

The unique circumstances of Alaska Native villages and their inability to qualify for assistance under a variety of federal flooding and erosion programs may require special measures to ensure that the villages receive certain needed services. Alaska Native villages, which are predominately remote and small, often face barriers not commonly found in other areas of the United States, such as harsh climate, limited access and infrastructure, high fuel and shipping prices, short construction seasons, and ice-rich permafrost soils. In addition, many of the federal programs to prevent and control flooding and erosion are not a good fit for the Alaska Native villages because of the requirement that economic costs of the project not exceed the economic benefits. Federal and Alaska state officials and Alaska Native village representatives that we spoke with identified several alternatives for Congress that could help mitigate the barriers that villages face in obtaining federal services.

These alternatives include (1) expanding the role of the Denali Commission to include responsibilities for managing a flooding and erosion assistance program, (2) directing the Corps and NRCS to include social and environmental factors in their cost/benefit analyses for projects requested by Alaska Native villages, and (3) waiving the federal cost-sharing requirement for flooding and erosion projects for Alaska Native villages. In addition, GAO identified a fourth alternative—authorizing the bundling of funds from various agencies to address flooding and erosion problems in these villages. Each of these alternatives has the potential to increase the level of federal services provided to Alaska Native villages and can be considered individually or in any combination. However, adopting some of these alternatives will require consideration of a number of important factors, including the potential to set a precedent for other communities and programs as well as resulting budgetary implications. While we did not determine the cost or the national policy implications associated with any of the alternatives, these are important considerations when determining appropriate federal action.

EXHIBIT E (Part 2 of 2)

Expand the Role of the Denali Commission

Congress may want to consider expanding the role of the Denali Commission by directing that federal funding for flooding and erosion studies and projects in Alaska Native villages go through the commission. Currently, the Denali Commission does not have explicit responsibility for flooding and erosion programs. This alternative would authorize the Denali Commission to establish a program that conducts studies and constructs projects to mitigate flooding and control erosion in Alaska Native villages that would otherwise not qualify under Corps and NRCS flooding and erosion programs. The commission could set priorities for its studies and projects and respond to the problems of those villages most in need, and it could enter into a memorandum of agreement with the Corps or other related agencies to carry out these studies and projects. One of the factors to consider in adopting this alternative is that additional funding may be required.

This alternative is similar to the current proposal in S. 295 that would expand the role of the Denali Commission to include a transportation function.[21] S. 295 would authorize the commission to construct marine connections (such as connecting small docks, boat ramps, and port facilities) and other transportation access infrastructure for communities that would otherwise lack access to the National Highway System. Under the bill, the commission would designate the location of the transportation project and set priorities for constructing segments of the system.

Direct the Corps and NRCS to Include Social and Environmental Factors in Their Cost/Benefit Analyses

A second alternative is for Congress to direct the Corps and NRCS to include social and environmental factors in its cost/benefit analysis for flooding and erosion projects for Alaska Native villages. Under this alternative, the Corps would not only consider social and environmental factors, but would also incorporate them into its cost/benefit analysis. Similarly, NRCS for its Watershed Protection and Flood Prevention Program would also incorporate social and environmental factors into its cost/benefit analysis. To capture these factors even when they cannot be easily quantified, the Corps and NRCS may have to consider these factors explicitly. Several Alaska Native entities have raised this issue with the Corps and the Alaska congressional delegation. For example, the Native village of Unalakleet has led efforts to have the Corps revise its cost/benefit analysis. As part of these efforts, the village has worked with state and

[21] Denali Transportation System Act, S. 295, 108th Cong. (2003).

federal agencies; the Alaska Federation of Natives, which represents Native corporations statewide; and the Alaska congressional delegation. One implication of adopting this alternative for Alaska Native villages may be that it could set a precedent for flooding and erosion control projects in other communities.

This alternative is intended to benefit small and remote villages that often fail to qualify for assistance because the cost of the study or project exceeds the benefits. The number of villages that may be able to qualify for a study or project under this alternative will depend on the extent to which the Corps and NRCS incorporate social and environmental factors into their calculations. However, if more villages qualify for projects under this approach, the increase could have an impact on the amount of funds and resources that the Corps and NRCS have available for these efforts.

Congress is currently considering a bill that would direct the Corps to approve certain projects that do not necessarily meet the cost/benefit requirement. In H.R. 2557, the Corps would be authorized to provide assistance to communities with remote and subsistence harbors that meet certain criteria.[22] In particular, for studies of harbor and navigational improvements, the Secretary of the Army could recommend a project without the need to demonstrate that it is justified solely by net national economic development benefits, if the Secretary determines that, among other considerations, (1) the community to be served by the project is at least 70 miles from the nearest surface-accessible commercial port and has no direct rail or highway link to another community served by a surface-accessible port or harbor or is in Puerto Rico, Guam, Northern Mariana Islands, or American Samoa; (2) the harbor is economically critical such that over 80 percent of the goods transported through the harbor would be consumed within the community; and (3) the long-term viability of the community would be threatened without the harbor and navigation improvement. These criteria would apply to many remote and subsistence harbors in Alaska Native villages.

[22] H.R. 2557, §2011, 108th Cong. (2003).

Waive the Federal Cost-Sharing Requirement for Flooding and Erosion Projects

A third alternative is to waive the federal cost-sharing requirement for flooding and erosion projects for Alaska Native villages. As required by law, the Corps currently imposes a cost-share of between 25 and 50 percent of project planning and construction costs. These sums, which are generally in the hundreds of thousands of dollars, are difficult for villages to generate. This difficulty has been one of the more common criticisms of the Corps' program. For example, the village of Unalakleet had difficulty obtaining funding for its local cost-share requirement for a project. Adopting this alternative for Alaska Native villages would require an assessment of several factors, including setting a precedent for other flooding and erosion control projects in other communities as well as budgetary implications.

In H.R. 2557, Congress is considering waiving the cost-sharing provisions for studies and projects in certain areas. In this bill, the Secretary of the Army would be required to waive up to $500,000 of the local cost-sharing requirements for all studies and projects in several locations, including land in the state of Alaska conveyed to Alaska Native Village Corporations.

Authorize Bundling of Funds from Various Agencies to Respond to Flooding and Erosion Problems

Congress could also consider authorizing the bundling of funds from various agencies to respond to flooding and erosion in Alaska Native villages. Under this alternative, Alaska Native villages could consolidate and integrate funding from flooding and erosion programs from various federal agencies, such as the Bureau of Indian Affairs and the Department of Housing and Urban Development, to conduct an erosion study or to help fund the local cost share of a Corps project. Doing so would potentially allow Alaska Native villages to use available federal assistance for flooding and erosion more effectively and efficiently. By law, Indian tribal governments are currently allowed to integrate their federally funded employment, training, and related services programs from various agencies into a single, coordinated, comprehensive program that reduces administrative costs by consolidating administrative functions.[23] Many Alaska Native villages participate in this program.

[23]Indian Employment, Training and Related Services Demonstration Act of 1992, Pub. L. No. 102-477, 106 Stat. 2302 (1992).

Several bills have been introduced to authorize tribal governments also to bundle federal funding for economic development programs and for alcohol and substance abuse programs. For example, in the 106th, 107th, and 108th sessions of Congress, bills were introduced to authorize the integration and coordination of federal funding for community, business, and economic development of Native American communities.[24] Under these bills, tribal governments or their agencies may identify federal assistance programs to be integrated for the purpose of supporting economic development projects. Similarly, in the 107th and 108th Congresses, S. 210 and S. 285 were introduced to authorize, respectively, the integration and consolidation of alcohol and substance abuse programs and services provided by tribal governments.

Conclusion

Alaska Native villages that are not making plans to relocate, but are severely affected by flooding and erosion, must find ways to respond to these problems. However, many of these villages have difficulty finding assistance under several federal programs, largely because the economic costs of the proposed project to control flooding and erosion exceed the expected economic benefits. As a result, many private homes and other infrastructure continue to be threatened and are in danger from flooding and erosion. In addition, many Alaska Native villages that are small, remote, and have a subsistence lifestyle, lack the resources to help them respond to flooding and erosion. Given the unique circumstances of Alaska Native villages, special measures may be required to ensure that these communities receive assistance in responding to flooding and erosion.

Alaska Native villages that cannot be protected from flooding and erosion through engineering structures and must relocate face a particularly daunting challenge. These villages are working with federal and state agencies to find ways to address this challenge. Any potential solution, however, whether a single erosion protection project or full relocation, goes through stages of planning and execution that can take years to complete. In the interim, investment decisions must be made regarding delivery of services such as building new structures or renovating and upgrading existing structures. Such decisions for villages should be made in light of the status of their efforts to address flooding and erosion. We identified a number of instances where projects were approved and

[24]The bills introduced in the 106th, 107th, and 108th Congresses were S. 2052, S. 343, and S. 1528, respectively.

designed without considering a village's relocation plans. Investing in infrastructure that cannot be easily moved or may be costly to move may not be the best use of limited federal funds. It is encouraging that the Denali Commission is working on a policy to ensure that investments are made in a conscientious and sustainable manner for villages threatened by flooding and erosion. Successful implementation of such a policy will depend in part on its adoption by individual federal agencies that also fund infrastructure development in Alaska Native villages.

Recommendations for Executive Action

In order to ensure that federal funds are expended in the most effective and efficient manner possible, we recommend that the federal cochairperson of the Denali Commission, in conjunction with the state of Alaska cochairperson, adopt a policy to guide future investment decisions and project designs in Alaska Native villages affected by flooding and erosion. The policy should ensure that (1) the Commission is aware of villages' efforts to address flooding and erosion and (2) projects are designed appropriately in light of a village's plans to address its flooding and erosion problems.

Matter for Congressional Consideration

Determining the appropriate level of service for Alaska Native villages is a policy decision that rests with Congress. We present four alternatives that Congress may wish to consider as it deliberates over how, and to what extent, federal programs could better respond to flooding and erosion in Alaska Native villages. In any such decision, two factors that would be important to consider are the cost and the national policy implications of implementing any alternative or combination of alternatives. If Congress would like to provide additional federal assistance to Alaska Native villages, it may wish to consider directing relevant executive agencies and the Denali Commission to assess the cost and policy implications of implementing the alternatives that we have identified or others that may be appropriate.

Agency Comments and Our Evaluation

We provided copies of our draft report to the Departments of Agriculture, Defense, Health and Human Services, Housing and Urban Development, the Interior, and Transportation; the Denali Commission; and the state of Alaska. The Departments of Defense, Housing and Urban Development, and the Interior, as well as the Denali Commission and the state of Alaska, provided official written comments. (See appendixes IV through VIII,

respectively, for the full text of the comments received from these agencies and our responses.) The comments were generally technical in nature with few comments on the report's overall findings, recommendation, and alternatives. The Departments of Health and Human Services and Transportation provided informal technical comments, and the Department of Agriculture had no comments on the report. We made changes to the draft report, where appropriate, based on the technical comments provided by the seven entities that commented on the draft report.

The Denali Commission was the only entity to comment on our recommendation that the commission adopt an investment policy. The commission agreed with the recommendation and noted that such a policy should help avoid flawed decision making in the future. Furthermore, the commission commented that it was not sufficient for it alone to have an investment policy, but believed that all funding agencies should use a similar policy to guide investments. We acknowledge the commission's concerns that other funding agencies should also make sound investment decisions. As noted in our report, the Denali Commission has signed a memorandum of understanding with 31 federal and state agencies with the goal of systematic planning and coordination for investments in infrastructure, economic development, and training, and we believe that this memorandum could serve as a vehicle by which other federal agencies would follow the lead of the commission regarding decisions to invest in communities.

Of the four alternatives presented in the report, the alternative to funnel funding for flooding and erosion projects through the Denali Commission received the most comments. The Denali Commission, the U.S. Army (commenting on behalf of the Department of Defense), and the Department of Housing and Urban Development all raised some concerns about this alternative. The Denali Commission commented that it is not convinced that expanding its role to include responsibilities for managing a flooding and erosion program is the appropriate response. The Army commented that the alternative to expand the role of the Denali Commission to mange a flooding and erosion program might exceed the capabilities of the organization. Lastly, the Department of Housing and Urban Development commented that the Denali Commission, as an independent agency, does not have the capacity to be fully integrated with the efforts of federal agencies to address this issue. Moreover, while each of these entities recognized the need for improved coordination of federal efforts to address flooding and erosion in Alaska Native villages, none of them provided any specific suggestions on how or by whom this should be accomplished. As

discussed in our report, the Denali Commission currently does not have the authority to manage a flooding and erosion program, and should Congress choose this alternative, the commission would need to develop such a program. Consequently, we still believe that expanding the role of the commission continues to be a possible option for helping to mitigate the barriers that villages face in obtaining federal services.

We are sending copies of this report to the Secretaries of Agriculture, the Army, Health and Human Services, Housing and Urban Development, the Interior, and Transportation, as well as to the federal and state cochairs of the Denali Commission, the Governor of the state of Alaska, appropriate congressional committees, and other interested Members of Congress. We will also make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staff have questions about this report, please contact me at (202) 512-3841. Key contributors to this report are listed in appendix IX.

Anu L. Mittal

Anu Mittal
Director, Natural Resources
and Environment

Objectives, Scope and Methodology

The fiscal year 2003 Conference Report for the military construction appropriation bill directed GAO to study Alaska Native villages affected by flooding and erosion. In response to this direction and subsequent discussions with committee staff, we (1) determined the extent to which Alaska Native villages are affected by flooding and erosion; (2) identified federal and Alaska state programs available to respond to flooding and erosion and assessed the extent to which federal assistance has been provided to Alaska Native villages; (3) determined the status of efforts, including cost estimates, to respond to flooding and erosion in the villages of Barrow, Bethel, Kaktovik, Kivalina, Koyukuk, Newtok, Point Hope, Shishmaref, and Unalakleet; and (4) identified alternatives that Congress may wish to consider when providing assistance for flooding and erosion of Alaska Native villages. In addition, during the course of our work we became concerned about the possible inefficient use of federal funds for building infrastructure in villages that were planning to relocate. As a result, we are including information regarding these concerns in this report.

To determine which Alaska Native villages are affected by flooding and erosion, we reviewed Alaska and federal agency reports and databases that contained information on flooding and erosion. We interviewed officials from Alaska and federal agencies, such as the Alaska Division of Emergency Services, the Alaska Department of Community and Economic Development, the U.S. Army Corps of Engineers, and the U.S. Department of Agriculture's Natural Resources Conservation Service, who are involved in addressing flooding and erosion problems. We also interviewed Alaska Native officials from the selected villages, as well as officials from Native village and regional corporations, such as Tikigaq, the Association of Village Council Presidents, and Kawarek. For the purposes of this report we defined an Alaska Native village as a village that (1) was deemed eligible as a Native village under the Alaska Native Claims Settlement Act and (2) has a corresponding Alaska Native entity that is recognized by the Department of the Interior's Bureau of Indian Affairs.[1]

We identified federal flooding and erosion programs by searching the *Catalog of Federal Domestic Assistance* and by using other information.

[1]A total of 220 Native villages were deemed eligible under ANCSA. However, seven of those villages do not have corresponding Alaska Native entities recognized by the Department of the Interior's Bureau of Indian Affairs. For a list of Indian entities recognized by the federal government, see 67 Fed. Reg. 46328 (July 12, 2002).

We reviewed applicable federal laws and regulations for these programs. We also reviewed program file records and interviewed federal program officials to determine the extent to which Alaska Native villages have been provided federal assistance. In addition, to determine the Alaska state programs that are available to villages for addressing flooding and erosion, we interviewed appropriate state officials from the Alaska Department of Transportation and Public Facilities, the Division of Emergency Services, and the Department of Community and Economic Development. We also discussed these programs and the assistance provided with selected village representatives.

While the committee directed us to include six villages, we added three more—Koyukuk, Newtok, and Shishmaref—based on discussions with congressional staff and with federal and Alaska state officials familiar with flooding and erosion problems. To determine the status of efforts, including cost estimates, to address flooding and erosion at these nine selected villages, we reviewed federal and state databases and studies. We also reviewed analyses performed by the Corps and by other federal, state, and local agencies. We visited only four villages—Bethel, Kivalina, Newtok, and Shishmaref—due to the high cost of travel in Alaska. We selected three of the four villages to visit that were in imminent danger (we visited Bethel because in order to reach Newtok we had to go through Bethel). We interviewed village representatives from each of the nine villages. We also interviewed state and federal officials involved in the efforts to address flooding and erosion for each of the nine villages. We identified and evaluated Corps studies that addressed these problems with particular attention to cost estimates. We also assessed the nature and applicability of these cost studies.

To determine what alternatives Congress may wish to consider in responding to flooding and erosion of Alaska Native villages, we interviewed local, state, and federal officials, officials from the Alaska Federation of Natives, and Kawarek representatives. During these interviews, we asked people to identify alternatives that they believed would address impediments to the delivery of flooding and erosion services. We also obtained and reviewed prior congressional bills that addressed Alaska Native issues.

We conducted our review from February 2003 through October 2003 in accordance with generally accepted government auditing standards.

ANCSA For-Profit Regional Corporations and Nonprofit Arms

Table 6 shows the list of the 13 regional corporations and the corresponding nonprofit arms. These nonprofit organizations provide social services to Alaska Native villages and also help Alaska Natives respond to problems, including those dealing with flooding and erosion.

Table 6: List of ANCSA For-Profit Regional Corporations and Nonprofit Arms

For-profit regional corporation	Nonprofit organization
Ahtna, Inc.	Copper River Native Association
The Aleut Corporation	Aleutian Pribilof Island Association
Arctic Slope Regional Corporation	Arctic Slope Native Association
Bering Straits Native Corporation	Kawerak, Incorporated
Bristol Bay Native Corporation	Bristol Bay Native Association
Calista Corporation	Association of Village Council Presidents
Chugach Alaska Corporation	Chugachmiut
Cook Inlet Region, Inc.	Cook Inlet Tribal Council
Doyon, Limited	Fairbanks Native Association
Koniag, Inc.	Kodiak Area Native Association
NANA Regional Corporation, Inc.	Maniilaq Association
Sealaska Corporation	Central Council
Thirteenth Regional Corporation	No nonprofit organization

Source: GAO.

List of 184 Affected Alaska Native Villages by ANCSA Region

Ahtna

Cheesh-Na Tribe (formerly the Native Village of Chistochina)
Native Village of Chitina
Native Village of Gakona
Native Village of Tazlina

Aleut

Agdaagux Tribe of King Cove
Native Village of Akutan
Native Village of Atka
Native Village of Belkofski[a]
Native Village of False Pass
Native Village of Nelson Lagoon
Native Village of Nikolski
Pauloff Harbor Village[a]
Saint George Island (see Pribilof Islands Aleut Communities of St. Paul and St. George Islands)
Saint Paul Island (see Pribilof Islands Aleut Communities of St. Paul and St. George Islands)
Qagan Tayagungin Tribe of Sand Point Village
Qawalangin Tribe of Unalaska
Native Village of Unga[a]

Arctic Slope

Native Village of Barrow Inupiat Traditional Government (formerly Native Village of Barrow)
Kaktovik Village (aka Barter Island)
Native Village of Nuiqsut (aka Nooiksut)
Native Village of Point Hope
Native Village of Point Lay
Village of Wainwright

Bering Straits

Native Village of Brevig Mission
Chinik Eskimo Community (Golovin)
Native Village of Diomede (aka Inalik)
King Island Native Community[a]

Native Village of Koyuk
Nome Eskimo Community
Native Village of Saint Michael
Native Village of Shaktoolik
Native Village of Shishmaref
Village of Solomon
Stebbins Community Association
Native Village of Teller
Native Village of Unalakleet
Native Village of Wales
Native Village of White Mountain
Native Village of Elim
Native Village of Gambell
Native Village of Savoonga

Bristol Bay
Native Village of Chignik
Native Village of Chignik Lagoon
Chignik Lake Village
Village of Clark's Point
Curyung Tribal Council (formerly Native Village of Dillingham)
Egegik Village
Ekwok Village
Igiugig Village
Village of Iliamna
Ivanoff Bay Village
Kokhanok Village
Levelock Village
Manokotak Village
Naknek Native Village
New Koliganek Village Council (formerly Koliganek Village)
New Stuyahok Village
Newhalen Village
Nondalton Village
Pedro Bay Village
Native Village of Perryville

Native Village of Pilot Point
Native Village of Port Heiden
Portage Creek Village (aka Ohgsenakale)
South Naknek Village
Traditional Village of Togiak
Twin Hills Village
Ugashik Village

Calista
Akiachak Native Community
Akiak Native Community
Village of Alakanuk
Algaaciq Native Village (St. Mary's)
Yupiit of Andreafski
Village of Aniak
Asa'carsarmiut Tribe (formerly Native Village of Mountain Village)
Village of Atmautluak
Village of Chefornak
Chevak Native Village
Native Village of Chuathbaluk (Russian Mission, Kuskokwim)
Village of Crooked Creek
Native Village of Eek
Emmonak Village
Native Village of Georgetown
Native Village of Goodnews Bay
Native Village of Hooper Bay
Iqurmuit Traditional Council (formerly Native Village of Russian Mission)
Village of Kalskag
Native Village of Kasigluk
Native Village of Kipnuk
Native Village of Kongiganak
Village of Kotlik
Organized Village of Kwethluk
Native Village of Kwigillingok
Native Village of Kwinhagak (aka Quinhagak)
Lime Village

Village of Lower Kalskag
Native Village of Marshall (aka Fortuna Ledge)
Native Village of Mekoryuk
Native Village of Napaimute
Native Village of Napakiak
Native Village of Napaskiak
Newtok Village
Native Village of Nightmute
Nunakauyarmiut Tribe (formerly Native Village of Toksook Bay)
Native Village of Nunapitchuk
Orutsararmuit Native Village (aka Bethel)
Oscarville Traditional Village
Pilot Station Traditional Village
Native Village of Pitka's Point
Platinum Traditional Village
Village of Red Devil
Native Village of Scammon Bay
Village of Sleetmute
Village of Stony River
Tuluksak Native Community
Native Village of Tuntutuliak
Native Village of Tununak

Chugach
Native Village of Chanega (aka Chenega)
Native Village of Eyak (Cordova)
Native Village of Nanwalek (aka English Bay)
Native Village of Tatitlek

Cook Inlet Region
Ninilchik Village
Seldovia Village Tribe
Native Village of Tyonek

Doyon
Alatna Village

Allakaket Village
Anvik Village
Beaver Village
Birch Creek Tribe (formerly listed as Birch Creek Village)
Chalkyitsik Village
Circle Native Community
Native Village of Eagle
Evansville Village (aka Bettles Field)
Native Village of Fort Yukon
Galena Village (aka Louden Village)
Organized Village of Grayling (aka Holikachuk)
Holy Cross Village
Hughes Village
Huslia Village
Village of Kaltag
Koyukuk Native Village
Manley Hot Springs Village
McGrath Native Village
Native Village of Minto
Nenana Native Association
Nikolai Village
Northway Village
Nulato Village
Rampart Village
Native Village of Ruby
Shageluk Native Village
Native Village of Stevens
Takotna Village
Native Village of Tanacross
Native Village of Tanana
Telida Village
Native Village of Tetlin

Koniag

Village of Afognak[a]
Native Village of Akhiok

Native Village of Karluk
Native Village of Larsen Bay
Village of Old Harbor
Native Village of Ouzinkie

NANA
Native Village of Ambler
Native Village of Buckland
Native Village of Deering
Native Village of Kiana
Native Village of Kivalina
Native Village of Kobuk
Native Village of Kotzebue
Native Village of Noatak
Noorvik Native Community
Native Village of Selawik
Native Village of Shungnak

Sealaska
Angoon Community Association
Chilkat Indian Village (Klukwan)
Craig Community Association
Hoonah Indian Association
Hydaburg Cooperative Association
Organized Village of Kake
Organized Village of Kasaan
Klawock Cooperative Association
Organized Village of Saxman
Yakutat Tlingit Tribe

[a] Reported as vacant by the state of Alaska as of March 2003.

Comments from the Department of the Army

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
CIVIL WORKS
108 ARMY PENTAGON
WASHINGTON DC 20310-0108

26 NOV 2003

REPLY TO
ATTENTION OF

Ms. Anu K. Mittal
Director
Natural Resources and Environment
United States General Accounting Office
441 G Street, N.W.
Washington, D.C. 20548-0001

Dear Ms. Mittal:

This is the Department of Defense (DoD) response to the GAO draft report, "ALASKA NATIVE VILLAGES: Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance," dated November 5, 2003, (GAO Code 360300/GAO-04-142).

Comments on the draft report are enclosed.

Very truly yours,

John Paul Woodley, Jr.

John Paul Woodley, Jr.
Assistant Secretary of the Army
(Civil Works)

Enclosure

Alaska Native Villages - Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance.

1. General Comments:

Recommend organizing information in accordance with the following outline. The outline below addresses the basic requirements of this report. This should help in reducing the redundancy of information that is presently in this report and provide the reader a clear understanding of the focus and purpose of this study. The suggested outline below addresses the specific requirements that Congress requested GAO to study regarding Alaskan Native Villages affected by flooding and erosion:

Cover Sheet: Executive Summary

A. Introduction

B. Historical Background & Current Efforts Addressing Flooding & Erosion Related Issues

1. Barrow
2. Bethel
3. Kaktovik
4. Kivalina
5. Point Hope
6. Unalakleet
7. Koyukuk
8. Newtok
9. Shishmaref

C. Government Programs that may Provide Assistance in Addressing Flooding & Erosion Related Problems

1. Corps of Engineers
2. Natural Resource Conservation Service (NRCS)
3. Other Federal Agencies
4. State Agencies

D. Alternatives for Congress to Consider in Providing Assistance to Alaskan Native Villages for flooding and erosion related issues.

- Expand Role of Denali Commission
- Direct Corps and NRCS to consider social, cultural and environmental factors in cost benefit analysis for projects (Note: Recommend adding "cultural")
- Waive cost sharing requirement for Corps' flooding and erosion program
- Extend cost sharing waiver eligibility to include Alaska projects located on land conveyed to an Alaskan Native Village Cooperation & increase cost sharing waiver for Civil Works studies and projects.

2. The document does not adequately address FEMA programs to buy out substantially damaged properties. If these communities were in the FEMA national flood insurance program (NFIP), they could potentially qualify for buy-outs to reduce future flood damages. The report should state that approximately 93% of all Alaskans (587,000 out of a total population of 630,000) are able to participate in the N F I P (Alaska Department of Community Economic Development data). It should be noted that the communities that the report shows as having the greatest flooding problems (Kivilina, Aniak, Unalakleet, and Shishmaref) are all non-participants in the NFIP.

See comment 1.

3. The GAO report cites Corps policy on benefits exceeding cost. This is not a matter of policy, it is a legal requirement. The 1936 Flood Control Act requires benefits to exceed costs for flood control projects.

4. The GAO report might also consider:

- Changes in legislation to earmark some of the Federal income for the state (oil, timber or other natural resources revenues/royalties/taxes) to meet the non-Federal cost share (similar to proposals in coastal Louisiana).
- Adequacy of Corps' ability to pay provisions contained in Section 103(m) of WRDA 1986 - and possible adjustments.
- Funding the Denali Commission with specific provision that the funds can be used for non-Federal cost share and/or offset project costs.

5. The bundling of funds from various Federal agencies may help particularly in Barrow. The infrastructure is at risk from storm damage, shoreline erosion and flooding. About $500 million of Barrow's infrastructure is located in the floodplain. In particular, the road that separates the sewage lagoon and an old landfill from the sea is at risk, as well as the village's utility corridor. This underground corridor contains sewage water and power lines, and communication facilities for the community. Other Federal participants could be EPA to protect the Artic Ocean and village water from sewage pollution, FEMA for relocation assistance and HUD for providing minimally acceptable housing and also community infrastructure.

Now on pp. 3 and 4.

Page 4

6. Line 8-11, Sentence reading "Besides programs administered by the Corps of Engineers and Natural Resources Conservation Service, there are several other federal and state programs that can assist Alaska Native villages in responding to the consequence of flooding and erosion." Suggest that this sentence be revised to indicate that theses programs are limited in potential response, as very few of them can address the broad scale and spectrum of erosion and flooding issues that are threatening most Alaska Native villages.

7. The draft report states, "Even villages that meet the Corps' cost/benefit criteria may still fail to qualify if they cannot meet cost-share requirements for the project." This is very interesting especially since several of the villages had no trouble meeting the cost-share requirement for a

small boat harbor (Bethel - $600,000 being one on the study's list). The Alaska District shows on their web page shows forty-nine such harbor / navigation aid projects. Additionally, a number of these communities (Alaska Department of Community Economic Development web site) had little or no trouble in providing the cost-sharing amounts for projects funded from other Federal sources (such as BIA, FAA or HUD).

See comment 2.

8. The report criticizes the Denali Commission and HUD for funding a health clinic at Newtok using 2002 & 2003 funds while the city was planning to relocate. In the case of Kivalina, which is probably the furthest along on relocation, the first indication of relocation occurred in the early 1990's – over ten years ago. It is not realistic to expect a city to go without a health clinic for ten years.

9. Expanding the Denali Commission's charter to include responsibilities for managing flooding and erosion assistance appears as though it might exceed the capability of an organization that currently has in its charter only energy, health care, training, government coordination and other infrastructure. In FY02 almost 60% of its work was on energy projects with much of the remaining 40% going toward health care facilities. This is a large task in itself for approximately 288 towns and cities. It might be worthwhile to consider expanding its role in government coordination (i.e. community planning) in helping the smaller towns (say under 1,000 residents) in doing better planning.

Now on p. 4.

Page 5

10. Paragraph 1. The Bethel project also includes reinforcing the existing pipe-pile seawall and providing rock toe protection.

Now on pp. 5 and 6.

Page 6

See comment 3.

11. While it may be appropriate to have the Denali Commission comment on its ability to perform under an expanded role, it would also be appropriate for agencies that are presently tasked in that role to comment on the introduction of another agency into the mix.

12. Bullet points two and three may be more effectively addressed through the authorization of an Alaska Native Village erosion and flooding program.

13. Recommend adding to bullet point three or as a separate bullet the following:

Extend cost sharing waiver eligibility to include Alaska projects located on lands conveyed to an Alaskan Native Village Cooperation and increase current cost sharing waiver provision for Civil Works studies and projects. (Note: Cost sharing waiver provisions currently apply only to US Territories of Guam, American Samoa, Commonwealth of the Marianas Islands & the Virgin Islands. Current waiver is $200,000 for the study phase and $200,000 for the construction phase. A legislative proposal, originally submitted for Water Resources Development Act (WRDA) 2002, is currently under consideration for WRDA 2003. This proposal recommends language to include Alaska projects located on land conveyed to an Alaskan Native Village Cooperation as

an eligible entity and to increase cost sharing waiver to $500,000 for the study phase and $500,000 for the construction phase.)

14. The recommendations to direct the Corps to consider social and environmental factors in BCR analyses, and waive non-Fed cost-sharing, are caveated on page 39 and other locations, in that it recognizes there could be precedent setting risks and additional burdens on the Federal budget. The GAO report does not seem to recognize Ability to Pay provisions of law, for which many of these villages would probably qualify. The non-Federal share for structural solutions would likely be approximately 5%. The non-structural portion of a project is also subject to the ability to pay provisions; however, the GAO report does not recognize that there are current provisions of law that allow for cost-sharing at less than 25-50%.

Page 8

15. In paragraph 2, the second sentence should read as follows. *The loss of sea ice leaves coasts more vulnerable to waves, storm surges, and erosion.*

Page 9

16. This page and the previous page describe the historical context of the Alaska native people and the impacts of the present changing environment. These descriptions do not recognize the fact that the environment also was changing prior to European immigration to Alaska, and that the Alaska native people coped with those changes by being mobile. The impacts of the present changes are onerous because the mobility of the Alaska native tribes has been compromised by the growth in modern infrastructure at sites selected for subsistence activities, not modern infrastructure feasibility. The fact that this infrastructure has been agglomerated into communities at sites not selected or planned for longevity increases the cost of both protection and relocation activities by a very large amount.

17. In the list of groupings, recommend adding Siberian Yupik with Yup'k. The Siberian Yupik are the people of St. Lawrence Island. One other major group in Southeast Alaska is the Tsimshian.

Page 12

18. In the middle paragraph the second sentence says, "The U.S. Army Corps of Engineers has responsibility for planning ...... erosion protection and flood control structures." The Corps has been given authority to provide erosion protection and flood control structures under a specific set of requirements. However, the Corps has not been endowed with a trust responsibility to any individual or group to provide erosion protection and flood control structures (as compared to the Indian Health Service). This is important, as project authorizations are not based upon equitable distribution of support to all needs or at the discretion of the Corps, but rather on congressional authorization and appropriations. Accordingly, suggest changing the sentence to read as follows: "The Corps may study and/or construct erosion protection and flood control structures, provided it receives authority and appropriations from Congress to do so."

19. Also in paragraph 2, non-structural methodologies of the Corps erosion control and flood damage reduction should be mentioned. Please add the following after the second sentence. *Although in many instances, measures undertaken by the Corps are structural in nature, the Corps may also consider and implement both non-structural and relocation alternatives.*

Page 13

20. In paragraph 2, the wording suggests that all coastal and river villages are subject to erosion or flooding. Suggest rewording to state that many coastal and river villages are subject to erosion or flooding.

Page 15

21. In paragraph 1, after the second sentence, suggest inserting a sentence as follows: "Lack of sea ice also increases the distance over water, which can generate increased waves and storm surges."

22. Kivalina, at its present location, has no record of inundation or overtopping by storm surge or waves. Wave run-up has occurred to the line of seaward houses and sea spray crosses the island, but inundation of the village has not been recorded to date. Recent analysis of storm surge and wave activity, based upon recent lack of fall ice cover, indicates the probability of surge and wave action that could overtop the barrier island and demolish the village.

Now on p. 17.

Page 16

23. In paragraph 2, the report states, "For example, Barrow experiences an average temperature increase of 4.16 degrees for the 30-year period from 1971 to 2000, while Bethel experienced an increase of 3.08 degrees for the same time period." The report should specify whether the temperature change is Fahrenheit or Centigrade.

24. The report talks about the flooding as being tied partially to climatic changes and references a study done by the Alaska Climate Research Center. The report says it's an average temperature increase, while the actual web site results are listed as mean annual/seasonal temperatures. There is not a link back to the actual data used by the Center to determine its chart. Their web site does have two reports (at least abstracts) that indicate data different from what is reported in the GAO report. A more relevant comparison would be Degree Days from previous data (Say Marks or ASHRAE) compared to the Degree Day data currently on the NOAA web site for the weather station located at the Point Barrow Airfield. If there were in fact a warming trend, the number of degree-days today would be substantially less than for those reported in Marks or ASHRAE of the early 1970's. The **National Center for Atmospheric Research data** from the Barrow First Order Weather Station indicate an increase in total heating degree-days of 600 from 1991 to 1999 (their records do not indicate any data for degree-days for the years preceding about 1985). This would equate to an overall temperature increase on 1.3 degrees F.

Now on pp. 19 and 20.

Page 19

25. Table 2. For consistency with Table 3 & 4 and the main focus of this report to address flooding and erosion, recommend revising the title of Table 2 to read: "Corps Authorities that Address Problems Related to Flooding and Erosion". Under the Corps Continuing Authorities Program (CAP) the following program authorities would fall within this category (Section 107 and Section 204 deleted):

- Section 14 of the Flood Control Act of 1946
- Section 205 of the Flood Control Act of 1948
- Section 208 of the Flood Control Act of 1954
- Section 103 of the River and Harbor Act of 1962
- Section 111 of the River and Harbor Act of 1968

In addition to the Corps CAP, other Corps authorities that may address problems related to flooding and erosion include the following:

- Section 22 of the Water Resources Development Act of 1974, as amended. Provides authority for the Corps to assist states, local governments and other non-federal entities in the preparation of comprehensive plans for the development, utilization, and conservation of water and related land resources.

- Section 206 of the 1960 Flood Control Act (PL 86-645), as amended. The Flood Plain Management Services' Program provides technical services and planning guidance that is needed to support effective flood plain management.

- Section 203 of the Water Resources Development Act of 2000 allows the Corps to investigate (study only) water resources development projects that will benefit tribes and are located primarily within tribal land.

Now on p. 22.

Page 21

26. The Corps does have authority to make cost sharing adjustments based upon a community's ability to pay. (Section 103(m) of WRDA 1986, as amended).

Now on p. 26.

Page 24

27. The listed Alaska State programs are primarily federally funded national or state-specific programs (with a small state cost-share) administered by the state agency. This distinction is important, as the present laws do not allow these programs to provide for the required local cost-share of the federal programs administered by the Corps of Engineers. There are other programs that are available to Indian Reorganization Act (IRA) village governments that can be used to provide local cost-share funds, and a few programs that are available to village City governments (subdivisions of the state) to provide low levels of grant funds that may also be used as a local cost share.

Now on p. 29.

Page 26

28. In Table 5, under Newtok Village, include the following information under "Status of efforts": Under the Corps Planning Assistance to States Program the relocation study for Newtok is continuing.

Now on p. 34.

Page 30

29. In paragraph 2, it should be noted that the Corps is currently examining impacts of coastal erosion due to continued climate change and other factors in the following communities in Alaska: Bethel, Dillingham, Shishmaref, Kakatovik, Kivalina, Unalakleet, and Newtok under the Tribal Partnership Program, Section 203 of WRDA 2000. Congress provided $2 million for FY 2003.

Now on p. 37.

Page 33

30. First sentence after Point Hope. This has been written about the oldest continually inhabited area in North America on several web sites, but the original document it came from referred to the longest continually inhabited area in Northwest Alaska. It isn't the longest continually inhabited area in Alaska (e.g. Nikolski – 4,000 yrs.). Please change *North America* to *Northwest Alaska*.

Now on p. 39.

Page 35

31. The 5th line from the bottom of the page: "emergency, the village placed rock along 600 linear feet of the riverbank and dock." Bethel is too large for a village. It is a regional hub and is the size of a town rather than a village. The state of Alaska officially lists Bethel as a Second Class City.

Now on p. 42.

Page 39

32. Section: Direct the Corps and NRCS to Include Social and Environmental Factors in its Cost/Benefit Analysis. One thing to note is that Point Hope is also a nationally significant cultural site or a National Historic Landmark. Barrow has a National Historic Landmark, properties on the National Register of Historic Places, and numerous well-known sites eligible for the National Register. There are also cultural resources at Kivalina, Shishmaref, Unalakleet, and Kaktovik. Additional research would need to be done to determine if there are sites at Bethel, and Koyukuk that would be threatened. Newtok is a relatively recent occupation, so the significance of its cultural resources is not clear. The report might want to consider including cultural heritage sites in the cost/benefit analysis for flooding and erosion projects for Alaska Native villages as a consideration for Congress to evaluate.

Now on p. 44.

Page 40

33. Cost-benefit waiver legislation. The report refers to provisions of HR 2557 (not enacted). This bill, if enacted, would authorize harbor projects in certain remote areas without justification based on NED benefits. It is not clear why this provision is identified, since it is for navigation harbors, and not flooding/erosion. If the report is trying to make the point that this type of

legislation could be developed for flooding/erosion too, then the report should make that point more clear.

Now on p. 44.

Page 41

34. In paragraph 2, the document mentions H.R. 2557 that will waive various cost sharing provisions. This addresses a major issue, but may not capture the needs of the whole region for determining project justification and cost sharing. In several instances, Congress has developed regional or site specific programs to address certain issues that vary from the specific guidance of the traditional Corps programs, often times looking at the needs of rural communities. There may exist the need to develop a specific program for addressing the Tribal community erosion and flood control issues, through which relocation, cost sharing, and justification issues can be addressed. Other ideas include granting authorization for other Federal funds to be eligible to match funds from other Federal cost sharing programs.

Appendix III

See comment 4.

35. Please correct the following village names (correction in bold):

Ahtna:
Cheesh'Na Tribe (formerly the **Chistochina Village Council**) <–not formerly Native Village of Chistochina>
Change from Native Village of Chitina to **Chitina Traditional Village**
Change from Native Village of Gakona to **Gakona Village Council**

Aleut:
Pauloff Harbor Village **Council**
St. George Island **Traditional Council**
Aleut Community of St. Paul Island
Qagan Tayagungin Tribe of Sand Point (remove Village)
Change Native Village of Unga to **Unga Tribal Council**

Arctic Slope:
Change Kaktovik Village to **Native Village of Kaktovik**

Bering Straits:
Native Village of Solomon
Teller Traditional Council

Bristol Bay**:**
Clark's Point Village Council
Curyung **Native Village** Council
Egetik Village **Council**
Ekwok Village **Council**
Igiugig Village **Council**
Ivanoff Bay Village **Council**

Kokhanok Village **Council**
Levelock Village **Council**
Manokotak Village **Council**
New Koliganek Village Council (formerly Koliganke Village **Council**)
New Stuyahok Village **Council**
Newhalen **Tribal Council**
Nondalton **Tribal Council**
Pedro Bay Village **Council**
Pilot Point Village Council
Port Heiden Village Council
Portage Creek Village **Council** (aka Ohgsenakale **Tribe**)
South Naknek Village **Council**
Togiak Traditional Council
Twin Hills Village **Council**
Ugashik **Traditional** Village **Council**

GAO's Comments

The Army commented on our alternative to expand the role of the Denali Commission, which is discussed in the Agency Comments and Our Evaluation section of this report. We also modified the report on the basis of the technical comments that the Army gave us, as appropriate. In addition, discussed below are GAO's corresponding detailed responses to some of the Army's comments.

1. We disagree with the Corps' statement that the Flood Control Act of 1936 requires benefits to exceed costs for flood control projects. The pertinent provision of the act states that "it is the sense of Congress that . . . the Federal Government should improve or participate in the improvement of navigable waters or their tributaries . . . if the benefits . . . are in excess of the estimated costs." 33 U.S.C. § 701a. This provision, while setting out a statement of Congressional policy, does not establish a legal requirement that benefits exceed costs, nor does it prohibit carrying out a project where costs exceed benefits. We have included a reference to this provision in the report's discussion of the Corps' guidelines for evaluating water resource projects.

2. We agree that it is not realistic for a village to go without a health clinic for 10 years. Our report states that development and maintenance of critical infrastructure, such as health clinics and runways, is necessary as villages find ways to address flooding and erosion. However, given limited federal funds, agencies must explore potentially less costly options for meeting a village's needs until it is able to relocate.

3. As noted in our report, if Congress decides to provide additional federal assistance to Alaska Native villages, it may wish to consider directing relevant executive agencies as well as the Denali Commission to assess the cost and policy implications of implementing the alternatives.

4. The names for the Alaska Native entities used in appendix III of this report are from the official list of federally recognized Indian entities published by the Department of the Interior in the *Federal Register* (see 67 Fed. Reg. 46328, July 12, 2002).

Comments from the Department of the Interior

United States Department of the Interior

OFFICE OF THE ASSISTANT SECRETARY
POLICY, MANAGEMENT AND BUDGET
Washington, D.C. 20240

NOV 25 2003

Anu Mittal
Director, Natural Resources and Environment
U.S. General Accounting Office
441 G Street, NW
Washington, DC 20548

Dear Ms. Mittal:

Thank you for the opportunity to review and comment on GAO's Draft Report entitled, "Alaska Native Villages: Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance" (GAO-04-142).

Although the draft report does not contain any formal recommendations to the Department of the Interior, (Department) the Department may be able to assist the Denali Commission or other federal agencies tasked by the Congress to develop and implement solutions and alternatives that will be identified in the future.

Several of the Department's bureaus have had an opportunity to review the draft report, including representatives of the Bureau of Indian Affairs, the Fish and Wildlife Service, and the Bureau of Land Management. It is their consensus that they would welcome the opportunity to assist in identifying solutions. The solution to the problem presented in the report will take a comprehensive and coordinated effort by all affected parties.

In closing, I want to again thank you for the opportunity to review the report. The cadre of issues and impacts documented in the draft report is overwhelming.

Sincerely,

P. Lynn Scarlett
Assistant Secretary
Policy Management and Budget

ENCLOSURE

Department of the Interior
Comments on GAO Draft Report entitled,
"Alaska Native Villages: Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance"
(GAO-04-142)

General Comments:

Our records (and the State's online Corporation's Database) indicate that some of the Regional Corporations have slightly different names from those listed. We believe the corporate names should be corrected as shown below, to be consistent.

The Aleut Corporation
Cook Inlet Region, Inc.
Koniag, Inc.
NANA Regional Corporation, Inc.

Specific Comments:

Page 2, first sentence - misplaced comma between the words "local" and "agencies."

Now on p. 29.

Page 26, Table 5, The status of the Newtok exchange needs to be updated.

Now on pp. 34 and 35.

Page 31, First sentence, starting with "Legislation that would covey ... "needs to be corrected and updated. Perhaps something like, "Legislation that would authorize the conveyance to Newtok of both the surface and subsurface estate of specified federal lands on nearby Nelson Island in exchange for land the village currently owns or would receive title to under ANCSA, has passed the House and Senate (the President's signature is expected within two weeks or the bill has recently been enacted)." The point is that the status of the legislation needs to be as current as possible, and Newtok is giving up two parcels–selections on Baird Inlet Island as well as conveyed lands and selections at the Aknerkochik location.

Comments from the U.S. Department of Housing and Urban Development

U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
WASHINGTON, DC 20410-5000

ASSISTANT SECRETARY FOR
PUBLIC AND INDIAN HOUSING

NOV 25 2003

MEMORANDUM FOR: Anu K. Mittal, Director, Natural Resources and Environment, General Accounting Office

FROM: Michael Liu, Assistant Secretary for Public and Indian Housing, P

SUBJECT: Comments on GAO Draft Report, "Alaska Native Villages: Most are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance"

The Department would like to thank GAO for its review of Alaska Native villages affected by flooding and erosion.

The Draft Report presents a sketch of the seriousness of the issue and the feasibility of alternatives for responding to the flooding and erosion problem. The review found that flooding and erosion affect 86 percent of Alaska Native villages. The Department shares the concern of GAO regarding the insufficient coordination of federal agencies that have involvement with this issue. However, the Department is not prepared to endorse GAO's suggestion that the Denali Commission manage federal funds for flooding and erosion problems. We have concerns that the Denali Commission, as an independent agency, does not have the capacity to be fully integrated with the efforts of federal agencies to address this issue. Careful consideration should be given to the financial and managerial capacity of any federal entity that may be considered to coordinate federal funds for flood and erosion control affecting Alaska Native villages.

The Department regards this study as an important resource in the continuing effort to meet the challenge of maintaining a safe and decent environment for Alaska Natives living along the coastline and rivers.

cc: Jeff Malcolm, Assistant Director, Natural Resources and Environment, GAO

www.hud.gov espanol.hud.gov

Comments from the Denali Commission

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

DENALI COMMISSION
510 "L" Street, Suite 410
Anchorage AK 99501

(907) 271-1414
Fax (907) 271-1415
Toll Free (888) 480-4321
www.denali.gov

November 10, 2003

Anu K. Mittal, Director
Natural Resources and Environment
United States General Accounting Office
441 G Street, Rm. 2T23A
Washington, D.C. 20548

Dear Ms. Mittal:

We very much appreciate the opportunity to comment on the draft report concerning flooding and erosion of Alaska Native Villages. In general, we believe the report does a good job of framing the issue and capturing the relevant information concerning this very serious problem. The magnitude of this problem, depending on the alternative(s) selected to address it, is measured in terms of hundreds of millions and possible billions of dollars.

Alternatives for addressing the problem range from moving imminently threatened villages to a new location to simply allowing individual villagers to relocate to other existing communities. There are significant costs associated with either approach, and with either approach there are likely to be interim investment decisions that have to be made.

We recognize the error that was made in the decision to fund a new clinic in Newtok. As pointed out in the report, the Commission's draft Investment Policy should help avoid similar flawed decision making in the future. We are confident that the principles upon which the Policy is based are sound, but its efficacy depends on available and accurate information. Community based, regionally supported comprehensive planning is critical to the sustainability of any public works project in rural Alaska. We will continue to seek the State of Alaska and other agencies' collaboration in making such planning effective.

Additionally it is not sufficient for the Denali Commission alone to have an Investment Policy. To ensure that investments are made in a conscientious and sustainable manner, we believe that all funding agencies should use a similar policy to guide investments. Otherwise communities will shop for the funding agency with the most permissive rules for funding.

As one alternative, the report recommends an expanded role for the Denali Commission to include responsibilities for manage a flooding and erosion assistance program. We are not convinced that a new program is the appropriate response.

For the four villages identified as being in imminent danger from flooding or erosion, prevention or minimization of flooding is very likely neither technically nor financially viable. If that is the case, then either a wholesale relocation of the village or allowing the community members to relocate among other more sustainable communities appears to be the only potentially viable solutions. Each community must make their own case by case decisions.

Wholesale relocation may not be financially viable, which would leave only the option of allowing community members the choice of going without publicly funded infrastructure or moving to where such infrastructure is sustainable. In some cases, the community High School is the most critical public infrastructure weighing heavily in such individual family decision making.

Relocation of an entire community requires some organization to plan and direct the myriad of actions involved. That organization need not necessarily be a federal agency.

With the foregoing in mind, the Commission offers the following recommendations:

See comment 1.

1. We believe that adequate information currently exists to determine whether preventing or minimizing flooding and erosion is technically and/or financially feasible. I recommend that the federal responsibility for such feasibility analysis is appropriately charged to the leadership of the Corps of Engineers.
2. If mitigation measures are not feasible, relocation must be a collaborative process. I believe tribal, local, state, federal and non-profit organizations must be consulted, and criteria established for each element of cost associated with any relocation program. Once established, such cost criteria must be weighed in the context of the only two options available – relocation of the entire community or relocation of individual families to other existing communities. Members of a threatened community should be provided adequate information in order to make informed choices.
3. Roles, responsibilities and functions must be clearly articulated under one comprehensive planning process. No agency should be allowed to act without concurrence and coordination with all agencies affected by such actions.
4. I concur with recommendations to review national criteria with an eye towards providing greater flexibility for the Alaska District of the Corps of Engineers to address Alaska's unique rural community flooding and erosion challenges.

See comment 2.

5. There should be a much larger role outlined for borough and State governments. While it is true that neither borough nor State governments is likely to be significant contributors of funding to address this issue, they can and should play a very central role in developing response strategies, in helping to prioritize the use of scarce resources, and in planning and helping to execute appropriate responses. If the appropriate response is the dispersion of the population to existing communities, borough and State government should play the lead role with little or no involvement from the federal government.
6. The report should strongly encourage all federal and state agencies to adopt an investment policy similar to that being developed by the Denali Commission, particularly for the expenditure of federal funds. Regardless of which approach to this problem is pursued, such a policy will help to ensure consistency and prudent use of limited available resources.

Again, we appreciate the opportunity to comment and will be happy to respond to any questions our comments may generate.

Sincerely,

Jeff Staser
Federal Co-chair

GAO's Comments

The Denali Commission commented on our recommendation and the alternative to expand its role, both of which are discussed in the Agency Comments and Our Evaluation section of this report. In addition, discussed below are GAO's corresponding detailed responses to some of the Denali Commission's general comments.

1. We agree that the Corps can determine whether preventing or minimizing flooding and erosion is technically and financially feasible. Under the Tribal Partnership Program, authorized by section 203 of the Water Resources Development Act of 2000 (Pub. L. No. 106-541, 114 Stat. 2572, 2588-2589 (2000)), the Corps is currently examining impacts of coastal erosion due to continued climate change and other factors in the Alaska Native villages of Bethel, Dillingham, Shishmaref, Kaktovik, Kivalina, Unalakleet and Newtok. Congress provided $2 million for these activities in fiscal year 2003. However, other federal agencies, such as the NRCS, also have the ability to conduct feasibility analyses.

2. We acknowledge the commission's desire for a larger role for Alaska state and local governments in developing and executing response strategies and in helping to prioritize the use of scarce resources. However, whether or not the state and local governments choose to expend their own resources to become more involved in responding to flooding and erosion issues is entirely a state or local government decision. Since this decision would involve the expenditure of state or local government funds, rather than federal funds, it is outside the scope of our report.

Comments from the State of Alaska

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

FRANK H. MURKOWSKI
GOVERNOR
GOVERNOR@GOV.STATE.AK.US

STATE OF ALASKA
OFFICE OF THE GOVERNOR
JUNEAU

P.O. BOX 110001
JUNEAU, ALASKA 99811-0001
(907) 465-3500
FAX (907) 465-3532
WWW.GOV.STATE.AK.US

November 21, 2003

Ms. Anu K. Mittal, Director
Natural Resources and Environment
United States General Accounting Office
441 G Street, Room 2T23A
Washington, DC 20548

Dear Ms. Mittal:

This is in response to your draft report to Senator Ted Stevens regarding Alaska native villages affected by flooding and erosion. The State of Alaska recognizes that many communities in the state are threatened by erosion from ocean tidal activity and river flooding. Some communities are in imminent danger and require federal assistance. We are encouraged that the GAO has recognized the dilemma these communities face and is committed to identifying alternatives that Congress may consider in providing assistance.

Comments for the Denali Commission are in appendix VII.

Enclosed for your review are responses from the Denali Commission, Department of Community and Economic Development, and the Division of Emergency Services. I sincerely appreciate the time and effort invested in preparing this report as well as the opportunity to comment.

Sincerely,

Michael A. Nizich
Deputy Chief of Staff

Enclosures

Appendix VIII
Comments from the State of Alaska

STATE OF ALASKA

FRANK MURKOWSKI, GOVERNOR

DEPARTMENT OF MILITARY AND VETERANS AFFAIRS
DIVISION OF HOMELAND SECURITY AND EMERGENCY MANAGEMENT

P.O. Box 5750
Ft. Richardson, AK 99505-5750
Phone: (800) 478-2337
Fax: (907) 428-7009
www.ak-prepared.com

Nov 20, 2003

Mr. Jeff Malcolm,
Assistant Director
Natural Resources and Environment
US General Accounting Office

Mr. Malcolm,

I represent the State of Alaska, Division of Emergency Services (DES), and I have reviewed your Draft Report to Congressional Committees entitled *ALASKA NATIVE VILLAGES, Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance.* I submit the following comments for consideration.

See comment 1.

- DES has some concern about how the nine "at risk" communities in the study were determined and why there were only nine. Some of the nine communities studied may not be in the top nine communities at risk from flooding and erosion and others at greater risk from flooding and erosion may not be included.

- Page 12. The statement in the second paragraph that identifies the Division of Emergency Services as the first to respond to state disaster declarations dealing with flooding and erosion is not accurate. Local communities are the first to respond to disasters. The state, through DES, responds only when local communities are unable to handle the situation themselves and request our assistance.

Now on p. 26.

- Page 24. The fifth bullet of the second paragraph identifies DES as "the state agency that responds first . . . " It would be more accurate to say that DES "is the state agency that, when assistance is requested, coordinates the response to emergencies . . . " Also, the last sentence of the fifth bullet needs further defined and should more accurately read as follows. "With authorization from the Governor, the state Disaster Relief Fund can make up to $1 million (without Legislative approval) available to communities recovering from a state declared disaster. Substantially more funding may be available, with Legislative approval, for Presidential Disaster Declarations, for which the state is obligated to pay a 25% funding match."

See comment 2.
Now on p. 42.

- Page 38. The last paragraph needs to better define the recommendation to expand the Denali Commission's role in providing flood and erosion assistance and its relationship to FEMA and state disaster response and recovery. The Denali Commission does not currently have a role in disaster response or recovery.

Now on p. 43.

- Page 39. The second paragraph, sixth sentence states that the Alaska Federation of Natives represents Native corporations statewide. This is not an accurate statement, as they do not represent all Alaska Native corporations. To our knowledge, there is no single entity that represents all Alaska Native corporations.

Thank you for the opportunity to review and comment on this GAO study. If you have any questions, please contact me at 907-428-7030.

Sincerely,

James F. Butchart

James F. Butchart
Deputy Director
Office of Emergency Management

Frank H. Murkowski, Governor

Alaska **Department of Community and Economic Development**

Division of Community Advocacy
550 W. 7th Avenue, Suite 1770, Anchorage, AK 99501-3510
Telephone: (907) 269-4580 • Fax: (907) 269-4563 • Text Telephone: (907) 465-5437
Email: questions@dced.state.ak.us • Website: www.dced.state.ak.us/cbd/

November 20, 2003

Anu K. Mittal, Director
Natural Resources and Environment
U.S. General Accounting Office
441 G Street, Room. 2T23A
Washington, D.C.

Dear Ms. Mittal:

Thank you for the opportunity to comment on the draft report regarding Alaska Native villages affected by flooding and erosion. As the State-coordinating department for floodplain management in Alaska – an agency that provides technical assistance without dedicated funds to mitigate these significant threats facing families and communities throughout Alaska - we are delighted to have had the congressionally mandated report prepared.

In general the report is well prepared given the short time frame and difficult mandate. We greatly appreciate the trips made to several of the villages by the study team in order to see first hand the problems faced by these communities.

The GAO recommendations may not go far enough to stress all alternatives are considered in current federal agency relocation planning efforts. Relocation options must also include sustainable community planning objectives, and what a 'no action' impact would be (e.g. would residents move to other communities if no new relocation site was developed?). Community relocation planning efforts need to be integrated into other community planning activities such as utility and airport master plans, economic development, or other comprehensive planning activities – many of which are funded by a mix of federal and state program dollars. "Sustainability" with regard to flooding and erosion meaning that a locale is able to withstand a severe natural event or a number of less severe events without incurring permanent degradation of property, diminished productivity, or reduced quality of life, and can afford locally to manage the level of damage that may occur.

The following comments are directed to specific areas in the report:

The 3rd paragraph, line three states: *"Relocation is a daunting process that may take several years to accomplish for these villages."* The daunting process is correct. From

"Promoting a healthy economy and strong communities"

Page Two

our experience, unless a funded, interdisciplinary, systematic approach to relocation is undertaken to assist these most threatened communities, structures will continue to be temporarily moved back to avoid loss but relocation has not, and will not, occur in 'several years.' Relocation has been a topic of discussion and study for Kivalina, Shishmaref and Newtok for at least two decades. We would like to see the federal disaster assistance programs included in the many assistance mechanisms that will be needed to address the relocation needs of these most threatened Alaska villages. In particular, the Flood Mitigation Assistance Program which GAO credits (page 29) as funding the move of 14 homes in Shishmaref after the 1997 storm, is now limited by the Federal Emergency Management Agency guidance only to "repetitive loss structures" as eligible rather than including "structures subject to imminent collapse or subsidence as a result of erosion or flooding" as is allowable under the Congressional authorizing language. [1] This unfairly limits a viable federal funding mechanism that has successfully mitigated the loss of many structures in Shishmaref but currently can not be used.

Now on p. 32.

Page 3-4, repeating on pages 20-21, the report discusses the difficulty of villages to provide cost-share funds, which is a very real problem. What is not mentioned is that historically the State has provided the nonfederal matching funds for most Corps of Engineers (and other federal projects) and with the extreme budget deficits currently faced by the State of Alaska the matching funds have been severely limited.

Now on pp. 3, 22, and 23.

Page 4, line 6, repeating on page 24 2nd bullet states: *"…the Alaska Department of Community and Economic Development provides coordination, (funding) and technical assistance to communities to help reduce losses and damage from flooding and erosion."* Please delete "funding", as DCED assistance is limited. There is no dedicated State fund for relocation, erosion or structural flood control. A number of special legislative pass-through grants and Community Development Block Grants have been used to fund erosion studies and relocation planning projects but no direct general fund exists at the State level.

Now on pp. 4 and 26.

Page 1, repeating on page 3, and 13: By listing *184 out of 213 or 86% of Alaska Native villages "affected" by erosion because quantifiable data are not available for remote locations*, though true misses concerns expressed by this Division about the complexity of the erosion policy arena – and lack of quantifying terms - with regard to erosion. Probably all 213 villages are "affected" because erosion is a naturally occurring process. Data collection needs some framework for quantification. Standard(s) for measurement; erosion zone guidance and federal (or state) standards by which to judge erosion risk are needed. The national standard for designing, development and siting for the "100-year flood" event exists and is quantifiable and measurable. A standard for erosion, such as a distance measurement needs to be established (such as the life of the structure, which itself may need to be standardized - 50-year life for a house, etc.). Congress has provided

Now on pp. 2 and 13.

[1] See Section 1366(e) (5) Eligible Activities (A) of The National Flood Insurance Act of 196as Amended by the national Flood Insurance Reform Act of 1994.

Page Three

limited authorization to implement a coastal erosion management program [2] but this has not advanced to the level of Executive Orders for guiding federal floodplain and wetlands management.

"Imminent threat" was another term used in the report but the definition and varies among agencies (HUD did not consider Unalakleet erosion problems an "Imminent threat", whereas NRCS did.)

Now on pp. 4, 29, and 32.

Page 4, 3rd line, page 26 Table 5, and page 28: describes Corps cost estimates for Kivalina. Suggest verifying with the Corps or footnoting as to the source document, particularly the *cite "…up to $400 million for just the cost of building a gravel pad…"*

Page 10, line 2: Please rewrite to add wording (all CAPS) to this affect: *"Since most OF THE villages AFFECTED BY SEVERE FLOODING AND EROSION THAT ARE PLANNING FOR RELOCATION do not have running water, the washeteria plays an important role;…"*

Page 10, line 3: Consider qualifying statement: *"Because many village homes IN THE VILLAGES MOST IMPACTED BY EROSION AND FLOODING do not have sanitation facilities they rely on honey buckets – a five-gallon bucket that serves as a toilet- or a flush and haul system."* Federal agencies and the State of Alaska have invested heavily in improving rural sanitation but in many villages the sanitation system does not allow for sufficient volume or flow of water to allow for in-home bathing and laundry.

Page 11, line 1: Suggest changing "Most" to MANY delete DOCK OR as follows*: "Most river villages also have a barge landing area where goods are delivered to the community during the ice-free period."* Because of ice conditions very few villages have docks.

Page 13 repeats from cover and page 3.

Page 16, line 3: the referenced 1982 report. If this is the "Listing of Alaskan Communities for Documentation of Erosion Problems" prepared for DCED (then Department of Community and Regional Affairs), please credit this Department. The companion report to this listing was "Understanding and Evaluating Erosion Problems" 9/1982, for DCED.

Now on p. 26.

Page 24, 4th bullet please verify with Alaska Housing Finance Corporation to see if they have *"grants to persons in imminent danger of losing their homes"*.

Now on p. 26.

Page 24, last line please clarify sentence to read: *"According to state documents BETWEEN 1972 and 1991 the state spent over $40 million for EROSION CONTROL STATEWIDE."*

[2] *Managing Coastal Erosion*, National Research Council (Library of Congress CC # 89-13845)

Page Four

Now on p. 32.

Page 29 Add: *"After the 1997 fall storm, which was declared a state disaster, FEMA FLOOD MITIGATION ASSISTANCE PROGRAM GRANT FUNDS (75 % SHARE) ADMINISTERED AND MATCHED BY THE STATE (25% share), helped move 14 homes along the COASTAL BLUFF to another part of the village, and in 2002…"*

GAO staff during their research prepared a list of studies by village. Suggest the village specific bibliography be included in an Appendix to the Final Report for future reference. This kind of community specific research is time consuming to collect and would be a useful addition to this study.

Thank you for the opportunity to comment on this draft report. If you have questions about any of the Division's comments, please contact Christy Miller, floodplain management program coordinator on my staff at (907) 269-4567.

Sincerely,

Gene Kane
Director

cc: Al Clough, DCED Deputy Commissioner, Juneau

GAO's Comments

The state of Alaska provided technical comments from the Division of Emergency Services and the Department of Community and Economic Development, which we incorporated as appropriate. In addition, discussed below are GAO's corresponding detailed responses to some of the state's comments.

1. The fiscal year 2003 Conference Report for the military construction appropriation bill directed GAO to study at least six Alaska Native villages affected by flooding and erosion—Barrow, Bethel, Kaktovik, Kivalina, Point Hope, and Unalakleet—we added three more—Koyukuk, Newtok, and Shishmaref—based on discussions with congressional staff and with federal and Alaska state officials familiar with flooding and erosion problems.[1] As our report states, four of the nine villages, Kivalina, Koyukuk, Newtok and Shishmaref are in imminent danger from flooding and erosion. We agree that the remaining five villages may not be the most at risk from flooding and erosion.

2. It is not our intent to expand the role of the Denali Commission to include a disaster response and recovery component.

[1]H. R. Conf. Rep. No. 107-731, at 15 (2002).

GAO Contacts and Staff Acknowledgments

GAO Contacts

Anu Mittal, (202) 512-3841
Jeffery D. Malcolm, (202) 512-6536

Acknowledgments

In addition to those named above, José Alfredo Gómez, Judith Williams, and Ned Woodward made key contributions to this report. Also contributing to the report were Mark Bondo, John Delicath, Chase Huntley, Marmar Nadji, Cynthia Norris, and Amy Webbink.

GAO's Mission

The General Accounting Office, the audit, evaluation and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through the Internet. GAO's Web site (www.gao.gov) contains abstracts and full-text files of current reports and testimony and an expanding archive of older products. The Web site features a search engine to help you locate documents using key words and phrases. You can print these documents in their entirety, including charts and other graphics.

Each day, GAO issues a list of newly released reports, testimony, and correspondence. GAO posts this list, known as "Today's Reports," on its Web site daily. The list contains links to the full-text document files. To have GAO e-mail this list to you every afternoon, go to www.gao.gov and select "Subscribe to e-mail alerts" under the "Order GAO Products" heading.

Order by Mail or Phone

The first copy of each printed report is free. Additional copies are $2 each. A check or money order should be made out to the Superintendent of Documents. GAO also accepts VISA and Mastercard. Orders for 100 or more copies mailed to a single address are discounted 25 percent. Orders should be sent to:

U.S. General Accounting Office
441 G Street NW, Room LM
Washington, D.C. 20548

To order by Phone:	Voice:	(202) 512-6000
	TDD:	(202) 512-2537
	Fax:	(202) 512-6061

To Report Fraud, Waste, and Abuse in Federal Programs

Contact:

Web site: www.gao.gov/fraudnet/fraudnet.htm
E-mail: fraudnet@gao.gov
Automated answering system: (800) 424-5454 or (202) 512-7470

Public Affairs

Jeff Nelligan, Managing Director, NelliganJ@gao.gov (202) 512-4800
U.S. General Accounting Office, 441 G Street NW, Room 7149
Washington, D.C. 20548

United States
General Accounting Office
Washington, D.C. 20548-0001

Official Business
Penalty for Private Use $300

Address Service Requested

Presorted Standard
Postage & Fees Paid
GAO
Permit No. GI00

[redacted]

EXHIBIT F

DOE/EIA-0573(2006)

Emissions of Greenhouse Gases in the United States 2006

November 2007

Energy Information Administration
Office of Integrated Analysis and Forecasting
U.S. Department of Energy
Washington, DC 20585

Contacts

This report, *Emissions of Greenhouse Gases in the United States 2006*, was prepared under the general direction of John Conti, Director of the Office of Integrated Analysis and Forecasting, and Glen E. Sweetnam, Director, International, Economic, and Greenhouse Gases Division, Energy Information Administration. General questions concerning the content of this report may be directed to the National Energy Information Center at 202/586-8800.

Specific technical information concerning the content of the report may be obtained from Perry Lindstrom at 202/586-0934 (e-mail, perry.lindstrom@eia.doe.gov). Without the assistance of Science Applications International Corporation this report would not have been possible. In particular we would like to thank Keith Forbes, Michael Mondshine, Sarah Mudd-Simmons, and Richard Richards.

Specific questions about the report should be referred to the following analysts:

Overview	Paul McArdle	(paul.mcardle@eia.doe.gov,	202/586-4445)
Carbon Dioxide	Perry Lindstrom	(perry.lindstrom@eia.doe.gov,	202/586-0934)
Methane	Perry Lindstrom	(perry.lindstrom@eia.doe.gov,	202/586-0934)
Nitrous Oxide	Stephen Calopedis	(stephen.calopedis@eia.doe.gov,	202/586-1156)
High-GWP Gases	Stephen Calopedis	(stephen.calopedis@eia.doe.gov,	202/586-1156)
Land Use, Land-Use Change, and Forests	Paul McArdle	(paul.mcardle@eia.doe.gov,	202/586-4445)

For this report, activity data on coal and natural gas consumption and electricity sales and losses by sector were obtained from the October 2007 *Monthly Energy Review* (*MER*). Petroleum detail is now also available in published tables within the *MER*. Also, while generally in agreement with the *MER*, some data revisions were obtained from the *Electric Power Annual* that are not reflected in the October *MER*.

In keeping with current international practice, this report presents data on greenhouse gas emissions in million metric tons carbon dioxide equivalent. The data can be converted to carbon equivalent units by multiplying by 12/44.

Preface

Title XVI, Section 1605(a) of the Energy Policy Act of 1992 (enacted October 24, 1992) provides:

> *Not later than one year after the date of the enactment of this Act, the Secretary, through the Energy Information Administration, shall develop, based on data available to, and obtained by, the Energy Information Administration, an inventory of the national aggregate emissions of each greenhouse gas for each calendar year of the baseline period of 1987 through 1990. The Administrator of the Energy Information Administration shall annually update and analyze such inventory using available data. This subsection does not provide any new data collection authority.*

The first report in this series, *Emissions of Greenhouse Gases 1985-1990*, was published in September 1993. This report—the fifteenth annual report—presents the Energy Information Administration's latest estimates of emissions for carbon dioxide, methane, nitrous oxide, and other greenhouse gases. Most of these estimates are based on activity data and applied emissions factors and not on measured or metered emissions. A limited number of emissions estimates, such as for methane from coal mine ventilation, are obtained through direct measurement. The source of these estimates is documented in Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2006*, DOE/EIA-0638(2006) (to be published). The documentation, which according to EIA standards must be updated no later than 90 days after the publication of this report, will be available on line at www.eia.doe.gov/oiaf/1605/ggrpt.

What's New in This Report

This year's report is the first in a new, shorter format that focuses on inventory data and a summary of trends for each source category.

For combustion-related carbon dioxide emissions the partial combustion factor has been removed for all fossil fuels and sectors. This is in keeping with new international guidelines. Unless the carbon is consciously sequestered it is likely to oxidize over the next 100 years.

This is the first annual EIA emissions inventory that directly incorporates estimates of methane emissions from industrial wastewater treatment.

Whereas past inventories included chaparral ecosystems in California, much of that land fails to meet the definition of forest land and, consequently, has been removed from the estimates. As a result, the forest carbon stock estimates for California are lower than those in previous inventories, especially in the earlier years.

Contents

Tables

Figures

Greenhouse Gas Emissions Overview

Total Emissions

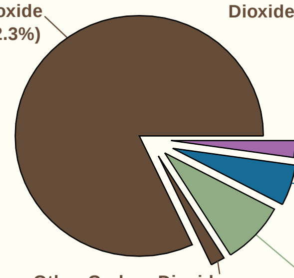
Summary

- Total U.S. greenhouse gas emissions in 2006 were 1.5 percent below the 2005 total—the first annual drop since 2001 and only the third since 1990.
- The total emissions reduction, from 7,181.4 million metric tons carbon dioxide equivalent ($MMTCO_2e$) in 2005 to 7,075.6 $MMTCO_2e$ in 2006, was largely a result of reductions in carbon dioxide (CO_2) emissions. There were smaller reductions in emissions of methane (CH_4) and man-made gases with high global warming potentials (high-GWP gases) (Table 1).
- U.S. carbon dioxide emissions in 2006 were 110.6 million metric tons (MMT) below their 2005 level of 6,045.0 MMT, due to favorable weather conditions; higher energy prices; a decline in the carbon intensity of electric power generation that resulted from increased use of natural gas, the least carbon-intensive fossil fuel; and greater reliance on non-fossil energy sources.
- Methane emissions totaled 605.1 $MMTCO_2e$ in 2006 (Figure 1), down by 2.3 $MMTCO_2e$ from 2005, with decreases in emissions from energy sources, agriculture, and industrial processes.
- U.S. emissions of high-GWP gases, which totaled 157.6 $MMTCO_2e$ in 2006, were 3.6 $MMTCO_2e$ below the 2005 total, as the result of a drop in hydrofluorocarbon (HFC) emissions.
- Emissions of nitrous oxide (N_2O), unlike the other greenhouse gases, increased by 10.6 $MMTCO_2e$ from 2005 to a 2006 total of 378.6 $MMTCO_2e$. The increase is attributed primarily to an increase of 9.9 $MMTCO_2e$ in emissions from agricultural sources.
- In 2005, the latest year for which data are available, U.S. land use, land-use change, and forestry activities resulted in total carbon sequestration of 828.5 $MMTCO_2e$, equal to 11.5 percent of U.S. greenhouse gas emissions in 2005.

U.S. Anthropogenic Greenhouse Gas Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	6,146.7	7,181.4	7,075.6
Change from 1990 (Million Metric Tons CO_2e)		1,034.7	928.9
(Percent)		*16.8%*	*15.1%*
Average Annual Change from 1990 *(Percent)*		*1.0%*	*0.9%*
Change from 2005 (Million Metric Tons CO_2e)			-105.8
(Percent)			*-1.5%*

Figure 1. U.S. Greenhouse Gas Emissions by Gas, 2006



Source: EIA estimates.

Table 1. U.S. Emissions of Greenhouse Gases, Based on Global Warming Potential, 1990, 1995, and 1999-2006

(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Carbon Dioxide	5,017.5	5,343.4	5,703.1	5,890.5	5,806.3	5,875.9	5,940.4	6,019.9	6,045.0	5,934.4
Methane	708.4	675.9	615.8	608.0	593.9	598.6	603.7	605.9	607.3	605.1
Nitrous Oxide	333.7	357.1	346.3	341.9	336.6	332.5	331.7	358.3	368.0	378.6
High-GWP Gases[a]	87.1	94.9	133.9	138.0	128.6	137.8	136.6	149.4	161.2	157.6
Total	**6,146.7**	**6,471.2**	**6,799.1**	**6,978.4**	**6,865.4**	**6,944.9**	**7,012.4**	**7,133.5**	**7,181.4**	**7,075.6**

[a]Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.

Sources: **Emissions:** EIA estimates. **Global Warming Potentials:** Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), pp. 38 and 388-389.

Greenhouse Gas Emissions Overview

U.S. Greenhouse Gas Intensity

Summary

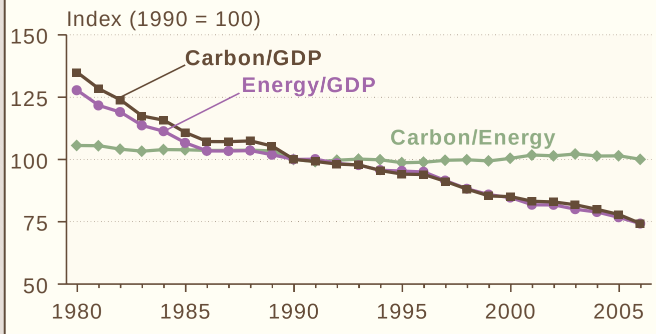
- From 2005 to 2006, the greenhouse gas intensity of the U.S. economy—measured as metric tons carbon dioxide equivalent ($MTCO_2e$) emitted per million dollars of gross domestic product (GDP)—fell by 4.2 percent, the largest annual decrease since the 1990 base year.
- Relatively robust economic growth in 2006, at 2.9 percent, coupled with a 1.5-percent drop in total greenhouse gas emissions, led to the decrease in greenhouse gas intensity (Table 2).
- Some of the factors that led to the decrease (such as weather) are variable; others (such as increased use of renewable energy for electricity generation) may indicate trends that are likely to continue.
- Since 2002, the base year for the Bush Administration's emissions intensity reduction goal of 18 percent in a decade, U.S. greenhouse gas intensity has fallen by an average of 2.5 percent per year, resulting in a total reduction of almost 10 percent from 2002 to 2006.
- The steady decrease in carbon intensity (carbon/GDP) has resulted mainly from reductions in energy use per unit of GDP (energy/GDP) rather than increased use of low-carbon fuels, as indicated by the carbon/energy ratio shown in Figure 2.

U.S. Greenhouse Gas Intensity, 1990, 2005, and 2006

	1990	2005	2006
Estimated Intensity ($MMTCO_2e$/GDP*)	864.2	652.6	625.1
Change from 1990 ($MMTCO_2e$/GDP*)		-211.6	-239.1
(Percent)		*-24.5%*	*-27.7%*
Average Annual Change from 1990 *(Percent)*		*-1.9%*	*-2.0%*
Change from 2005 ($MMTCO_2e$/GDP*)			-27.6
(Percent)			*-4.2%*

*U.S. gross domestic product (million 2000 dollars).

Figure 2. Intensity Ratios: Carbon/Energy, Energy/GDP, and Carbon/GDP, 1980-2006



Source: EIA estimates.

Table 2. U.S. Greenhouse Gas Intensity and Related Factors, 1990, 1995, and 1999-2006

	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Gross Domestic Product (Billion 2000 Dollars)	7,112.5	8,031.7	9,470.3	9,817.0	9,890.7	10,048.8	10,301.0	10,675.8	11,003.4	11,319.4
Greenhouse Gas Emissions ($MMTCO_2e$)	6,146.7	6,471.2	6,799.1	6,978.4	6,865.4	6,944.9	7,012.4	7,133.5	7,181.4	7,075.6
Greenhouse Gas Intensity ($MTCO_2e$ per Million 2000 Dollars)	864.2	805.7	717.9	710.8	694.1	691.1	680.8	668.2	652.7	625.1
Change from Previous Year (Percent)										
Gross Domestic Product	—	2.5	4.4	3.7	0.8	1.6	2.5	3.6	3.1	2.9
Greenhouse Gas Emissions	—	0.6	0.8	2.6	-1.6	1.2	1.0	1.7	0.7	-1.5
Greenhouse Gas Intensity	—	-1.9	-3.5	-1.0	-2.4	-0.4	-1.5	-1.8	-2.3	-4.2
Change from 2002 (Percent)[a]										
Cumulative	—	—	—	—	—	—	-1.5	-3.3	-5.6	-9.6
Annual Average	—	—	—	—	—	—	-1.5	-1.7	-1.9	-2.5

[a]The Bush Administration's emissions intensity goal calls for an 18-percent reduction between 2002 and 2012; achieving that goal would require an average annual reduction of slightly less than 2 percent over the entire period.

P = preliminary data.

Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006).

Sources: **Emissions:** EIA estimates. **GDP:** U.S. Department of Commerce, Bureau of Economic Analysis, web site www.bea.gov.

Greenhouse Gas Emissions Overview

Greenhouse Gas Emissions in the U.S. Economy

The diagram on page 4 illustrates the flow of U.S. greenhouse gas emissions in 2006, from their sources to their distribution across the U.S. end-use sectors. The left side shows CO_2 by fuel sources and quantities and other gases by quantities; the right side shows their distribution by sector. The center of the diagram indicates the split between CO_2 emissions from direct fuel combustion and electricity conversion. Adjustments indicated at the top of the diagram for U.S. territories and international bunker fuels correspond to greenhouse gas reporting requirements developed by the United Nations Framework Convention on Climate Change (UNFCCC).

CO_2. CO_2 emission sources include energy-related emissions (primarily from fossil fuel combustion) and emissions from industrial processes. The energy subtotal (5,890 $MMTCO_2e$) includes petroleum, coal, and natural gas consumption and smaller amounts from renewable sources, including municipal solid waste and geothermal power generation. The energy subtotal also includes emissions from nonfuel uses of fossil fuels, mainly as inputs to other products. Industrial process emissions (109 $MMTCO_2e$) include cement manufacture, limestone and dolomite calcination, soda ash manufacture and consumption, carbon dioxide manufacture, and aluminum production. The sum of the energy subtotal and industrial processes equals unadjusted CO_2 emissions (5,999 $MMTCO_2e$). The energy component of unadjusted emissions can be divided into direct fuel use (3,546 $MMTCO_2e$) and fuel converted to electricity (2,344 $MMTCO_2e$).

Non-CO_2 Gases. Methane (605 $MMTCO_2e$) and nitrous oxide (379 $MMTCO_2e$) sources include emissions related to energy, agriculture, waste management, and industrial processes. Other, high-GWP gases (158 $MMTCO_2e$) include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). These gases have a variety of uses in the U.S. economy, including refrigerants, insulators, solvents, and aerosols; as etching, cleaning, and firefighting agents; and as cover gases in various manufacturing processes.

Adjustments. In keeping with the UNFCCC, CO_2 emissions from U.S. Territories (61 $MMTCO_2e$) are added to the U.S. total, and CO_2 emissions from fuels used for international transport (both oceangoing vessels and airplanes) (126 $MMTCO_2e$) are subtracted to derive total U.S. greenhouse gas emissions (7,076 $MMTCO_2e$).

Emissions by End-Use Sector. CO_2 emissions by end-use sectors are based on EIA's estimates of energy consumption (direct fuel use and purchased electricity) by sector and on the attribution of industrial process emissions by sector. CO_2 emissions from purchased electricity are allocated to the end-use sectors based on their shares of total electricity sales. Non-CO_2 gases are allocated by direct emissions in those sectors plus emissions in the electric power sector that can be attributed to the end-use sectors based on electricity sales.

Residential emissions (1,234 $MMTCO_2e$) include energy-related CO_2 emissions (1,217 $MMTCO_2e$); and non-CO_2 emissions (17 $MMTCO_2e$). The non-CO_2 sources include direct methane and nitrous oxide emissions from direct fuel use. Non-CO_2 indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF_6 emissions related to electricity transmission and distribution, are also included.

Emissions in the **commercial** sector (1,287 $MMTCO_2e$) include both energy-related CO_2 emissions (1,056 $MMTCO_2e$) and non-CO_2 emissions (231 $MMTCO_2e$). The non-CO_2 emissions include direct emissions from landfills, wastewater treatment plants, commercial refrigerants, and stationary combustion emissions of methane and nitrous oxide. Non-CO_2 indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF_6 emissions related to electricity transmission and distribution, are also included.

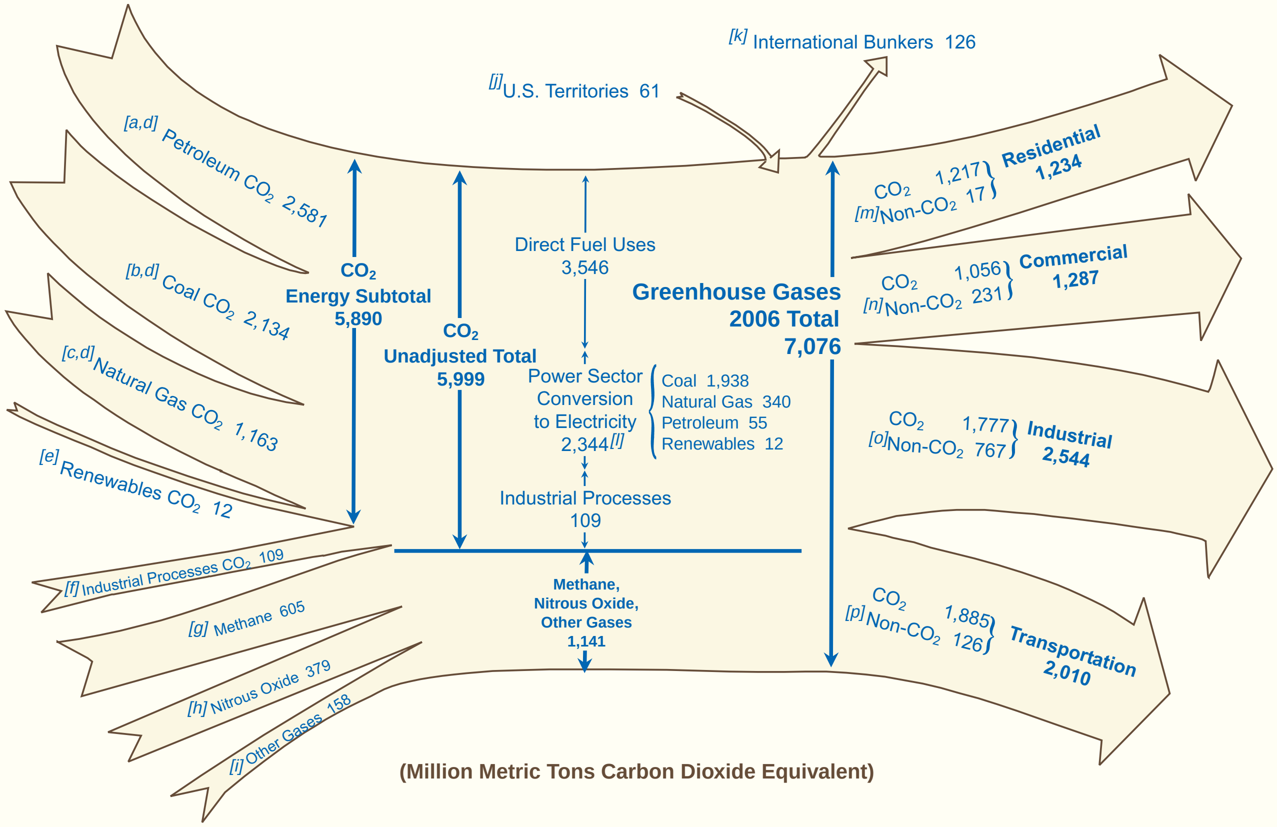
Industrial emissions (2,544 $MMTCO_2e$) include CO_2 emissions (1,777 $MMTCO_2e$)—which can be broken down between combustion (1,668 $MMTCO_2e$) and process emissions (109 $MMTCO_2e$)—and non-CO_2 emissions (767 $MMTCO_2e$). The non-CO_2 direct emissions include emissions from agriculture (methane and nitrous oxide), coal mines (methane), petroleum and natural gas pipelines (methane), industrial process emissions (methane, nitrous oxide, HFCs, PFCs and SF_6), and direct stationary combustion emissions of methane and nitrous oxide. Non-CO_2 indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF_6 emissions related to electricity transmission and distribution, are also included.

Transportation emissions (2,010 $MMTCO_2e$) include energy-related CO_2 emissions from mobile source combustion (1,885 $MMTCO_2e$); and non-CO_2 emissions (126 $MMTCO_2e$). The non-CO_2 emissions include methane and nitrous oxide emissions from mobile source combustion and HFC emissions from the use of refrigerants for mobile source air-conditioning units.

(continued on page 4)

Greenhouse Gas Emissions Overview

Greenhouse Gas Emissions in the U.S. Economy



(Million Metric Tons Carbon Dioxide Equivalent)

Diagram Notes

[*a*] CO_2 emissions related to petroleum consumption (includes 87.5 $MMTCO_2$ of non-fuel-related emissions).

[*b*] CO_2 emissions related to coal consumption (includes 0.5 $MMTCO_2$ of non-fuel-related emissions).

[*c*] CO_2 emissions related to natural gas consumption (includes 18.1 $MMTCO_2$ of non-fuel-related emissions).

[*d*] Excludes carbon sequestered in nonfuel fossil products.

[*e*] CO_2 emissions from the plastics portion of municipal solid waste (11.5 $MMTCO_2$) combusted for electricity generation and very small amounts (0.4 $MMTCO_2$) of geothermal-related emissions.

[*f*] Includes mainly direct process emissions. Some combustion emissions are included from waste combustion outside the electric power sector and flaring of non-marketed natural gas.

[*g*] Includes methane emissions related to energy, agriculture, waste management, and industrial processes.

[*h*] Includes nitrous oxide emissions related to agriculture, energy, industrial processes, and waste management.

[*i*] Includes hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

[*j*] Includes only energy-related CO_2 emissions from fossil fuels. Emissions are allocated to end-use sectors in proportion to U.S. ratios.

[*k*] Includes vessel bunkers and jet fuel consumed for international travel. Under the UNFCCC, these emissions are not included in country emission inventories. Emissions are subtracted from the transportation sector total.

[*l*] CO_2 emissions from electricity generation in the commercial and industrial sectors are included in those sectors.

[*m*]Non-CO_2: Direct stationary combustion emissions of methane and nitrous oxide plus indirect power sector emissions of methane, nitrous oxide, and other greenhouse gases.

[*n*] Non-CO_2: Direct stationary combustion emissions of methane and nitrous oxide plus indirect power sector emissions of methane, nitrous oxide, and other greenhouse gases. Additional direct emissions include emissions from landfills, wastewater treatment, and commercial refrigerants.

[*o*] Non-CO_2: Direct stationary combustion emissions of methane and nitrous oxide plus indirect power sector emissions of methane, nitrous oxide, and other greenhouse gases. In addition, all agricultural emissions are included in the industrial sector as well as direct process emissions of methane, nitrous oxide, and the other gases.

[*p*] Non-CO_2: Direct mobile combustion emissions of methane and nitrous oxide. Also, emissions related to transportation refrigerants are included.

Source: Estimates presented in this report. CO_2 emissions by end-use sector are based on EIA's estimates of energy consumption by sector and on industrial process emissions. CO_2 emissions from the electric power sector are allocated to the end-use sectors based on electricity sales to the sector. Non-CO_2 emissions by end-use sector are allocated by direct emissions in those sectors plus indirect emissions from the electric power sector allocated by electricity sales. Data are preliminary. Totals may not equal sum of components due to independent rounding.

(continued on page 5)

Greenhouse Gas Emissions Overview

Greenhouse Gas Emissions in the U.S. Economy

Distribution of Total U.S. Greenhouse Gas Emissions by End-Use Sector, 2006

Greenhouse Gas and Source	Sector				
	Residential	Commercial	Industrial	Transportation	Total
Carbon Dioxide	Million Metric Tons Carbon Dioxide Equivalent				
Energy-Related (adjusted)	1,216.8	1,056.1	1,668.0	1,884.7	**5,825.5**
Industrial Processes	—	—	108.8	—	**108.8**
Total CO_2	**1,216.8**	**1,056.1**	**1,776.8**	**1,884.7**	**5,934.4**
Methane					
Energy					
Coal Mining	—	—	64.7	—	**64.7**
Natural Gas Systems	—	—	150.8	—	**150.8**
Petroleum Systems	—	—	21.1	—	**21.1**
Stationary Combustion	8.1	0.1	0.5	—	**8.8**
Stationary Combustion: Electricity	0.1	0.1	0.1	—	**0.3**
Mobile Sources	—	—	—	4.8	**4.8**
Waste Management					
Landfills	—	146.7	—	—	**146.7**
Domestic Wastewater Treatment	—	15.9	—	—	**15.9**
Industrial Wastewater Treatment	—	—	8.5	—	**8.5**
Industrial Processes	—	—	2.4	—	**2.4**
Agricultural Sources					
Enteric Fermentation	—	—	114.6	—	**114.6**
Animal Waste	—	—	56.2	—	**56.2**
Rice Cultivation	—	—	9.1	—	**9.1**
Crop Residue Burning	—	—	1.2	—	**1.2**
Total Methane	**8.2**	**162.9**	**429.2**	**4.8**	**605.1**
Nitrous Oxide					
Agriculture					
Nitrogen Fertilization of Soils	—	—	226.7	—	**226.7**
Solid Waste of Animals	—	—	61.7	—	**61.7**
Crop Residue Burning	—	—	0.6	—	**0.6**
Energy Use					
Mobile Combustion	—	—	—	54.8	**54.8**
Stationary Combustion	0.8	0.3	4.5	—	**5.6**
Stationary Combustion: Electricity	3.3	3.2	2.5	—	**9.0**
Industrial Sources	—	—	13.8	—	**13.8**
Waste Management					
Human Sewage in Wastewater	—	5.9	—	—	**5.9**
Waste Combustion	—	—	—	—	**0.0**
Waste Combustion: Electricity	0.1	0.1	0.1	—	**0.4**
Total Nitrous Oxide	**4.3**	**9.6**	**309.9**	**54.8**	**378.6**
Hydrofluorocarbons (HFCs)					
HFC-23	—	—	14.5	—	**14.5**
HFC-32	—	0.4	—	—	**0.4**
HFC-125	—	22.1	—	—	**22.1**
HFC-134a	—	—	—	66.1	**66.1**
HFC-143a	—	23.0	—	—	**23.0**
HFC-236fa	—	2.9	—	—	**2.9**
Total HFCs	**0.0**	**48.4**	**14.5**	**66.1**	**129.0**
Perfluorocarbons (PFCs)					
CF_4	—	—	2.9	—	**2.9**
C_2F_6	—	—	3.4	—	**3.4**
NF_3, C_3F_8, and C_4F_8	—	—	0.6	—	**0.6**
Total PFCs	**0.0**	**0.0**	**6.9**	**0.0**	**6.9**
Other HFCs, PFCs/PFPEs	**—**	**6.1**	**—**	**—**	**6.1**
Sulfur Hexafluoride (SF_6)					
SF_6: Utility	4.5	4.3	3.3	—	**12.2**
SF_6: Other	—	—	3.4	—	**3.4**
Total SF_6	**4.5**	**4.3**	**6.7**	**0.0**	**15.5**
Total Non-CO_2	**17.1**	**231.3**	**767.2**	**125.6**	**1,141.2**
Total Emissions	**1,233.8**	**1,287.4**	**2,544.0**	**2,010.3**	**7,075.6**

Greenhouse Gas Emissions Overview

U.S. Emissions in a Global Perspective

Summary

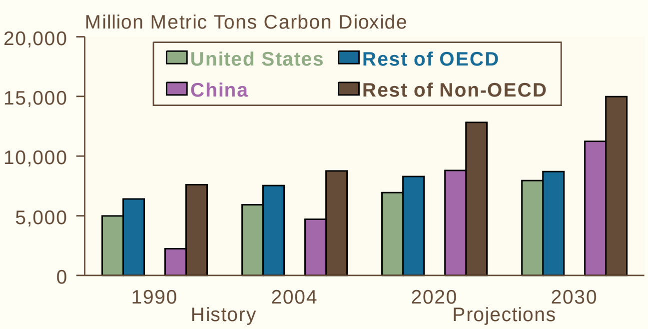
- In EIA's 2005 emissions inventory report, total U.S. energy-related carbon dioxide emissions in 2004 (including nonfuel uses of fossil fuels) were estimated at 5,923.2 MMT. With the 2004 world total for energy-related carbon dioxide emissions estimated at 26,922 MMT, U.S. emissions were about 22 percent of the world total (see Table 3 on page 7).
- Carbon dioxide emissions related to energy use in the mature economies of countries that are members of the Organization for Economic Cooperation and Development (OECD)—including OECD North America, OECD Europe, Japan, and Australia/New Zealand—are estimated at 13,457 MMT, or about one-half of the world total. With the remaining 50 percent of worldwide energy-related carbon dioxide emissions (13,465 MMT) coming from non-OECD countries, 2004 marked the first year in which global emissions were split evenly between the OECD and non-OECD economies (Figure 3).
- In EIA's *International Energy Outlook 2007* (*IEO2007*) reference case, projections of energy use and emissions are sensitive to economic growth rates and energy prices. Projections for a range of alternative growth and price scenarios are presented in *IEO2007*.
- U.S. energy-related carbon dioxide emissions are projected to increase at an average annual rate of 1.1 percent from 2004 to 2030, while emissions from the non-OECD economies are projected to grow by 2.6 percent per year. As a result, the U.S. share of world carbon dioxide emissions is projected to fall to 19 percent in 2030 (7,950 MMT out of a global total of 42,880 MMT) (Figure 4).

World Energy-Related Carbon Dioxide Emissions, 1990, 2004, and 2030

	1990	2004	2030*
Estimated Emissions (Million Metric Tons)	21,246	26,922	42,880
Change from 1990 (Million Metric Tons)		5,676	21,634
(Percent)		*26.7%*	*101.8%*
Average Annual Change from 1990 *(Percent)*		*1.7%*	*1.8%*
Change from 2004 (Million Metric Tons)			15,958
(Percent)			59.3%

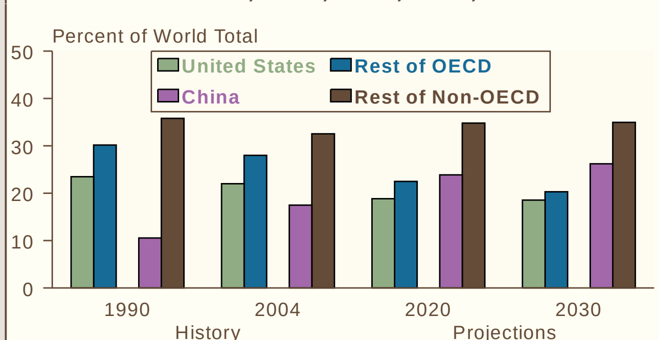
*EIA, *International Energy Outlook 2007.*

Figure 3. World Carbon Dioxide Emissions by Region, 1990, 2004, 2020, and 2030



Source: EIA, *International Energy Outlook 2007.*

Figure 4. Regional Shares of World Carbon Dioxide Emissions, 1990, 2004, 2020, and 2030



Source: EIA, *International Energy Outlook 2007.*

Greenhouse Gas Emissions Overview

U.S. Emissions in a Global Perspective

Table 3. World Energy-Related Carbon Dioxide Emissions by Region, 1990-2030
(Million Metric Tons Carbon Dioxide)

Region/Country	History[a]			Projections[a]					Average Annual Percent Change, 2004-2030
	1990	2003	2004	2010	2015	2020	2025	2030	
OECD									
OECD North America	**5,763**	**6,775**	**6,893**	**7,343**	**7,780**	**8,230**	**8,791**	**9,400**	**1.2**
United States[b]	4,989	5,800	5,923	6,214	6,589	6,944	7,425	7,950	1.1
Canada	474	589	584	648	659	694	722	750	1.0
Mexico	300	385	385	481	532	592	644	699	2.3
OECD Europe	**4,092**	**4,321**	**4,381**	**4,493**	**4,558**	**4,579**	**4,621**	**4,684**	**0.3**
OECD Asia	**1,543**	**2,129**	**2,183**	**2,269**	**2,353**	**2,423**	**2,495**	**2,569**	**0.6**
Japan	1,015	1,244	1,262	1,274	1,290	1,294	1,297	1,306	0.1
South Korea	238	475	497	523	574	614	649	691	1.3
Australia/New Zealand	291	410	424	472	490	516	549	573	1.2
Total OECD	**11,399**	**13,225**	**13,457**	**14,105**	**14,692**	**15,232**	**15,907**	**16,654**	**0.8**
Non-OECD									
Non-OECD Europe and Eurasia	**4,193**	**2,717**	**2,819**	**3,067**	**3,301**	**3,545**	**3,729**	**3,878**	**1.2**
Russia	2,334	1,602	1,685	1,809	1,908	2,018	2,114	2,185	1.0
Other	1,859	1,115	1,134	1,258	1,393	1,527	1,615	1,693	1.6
Non-OECD Asia	**3,627**	**6,479**	**7,411**	**9,711**	**11,404**	**13,115**	**14,759**	**16,536**	**3.1**
China	2,241	3,898	4,707	6,497	7,607	8,795	9,947	11,239	3.4
India	578	1,040	1,111	1,283	1,507	1,720	1,940	2,156	2.6
Other Non-OECD Asia	807	1,542	1,593	1,930	2,289	2,600	2,871	3,141	2.6
Middle East	**705**	**1,211**	**1,289**	**1,602**	**1,788**	**1,976**	**2,143**	**2,306**	**2.3**
Africa	**649**	**895**	**919**	**1,140**	**1,291**	**1,423**	**1,543**	**1,655**	**2.3**
Central and South America	**673**	**981**	**1,027**	**1,235**	**1,413**	**1,562**	**1,708**	**1,851**	**2.3**
Brazil	220	317	334	403	454	500	544	597	2.3
Other Central/South America	453	664	693	831	959	1,062	1,165	1,254	2.3
Total Non-OECD	**9,847**	**12,283**	**13,465**	**16,755**	**19,197**	**21,622**	**23,882**	**26,226**	**2.6**
Total World	**21,246**	**25,508**	**26,922**	**30,860**	**33,889**	**36,854**	**39,789**	**42,880**	**1.8**

[a]Values adjusted for nonfuel sequestration.
[b]Includes the 50 States and the District of Columbia.
Note: The U.S. numbers include carbon dioxide emissions attributable to renewable energy sources.
Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea/; and data presented in this report. **Projections:** EIA, *Annual Energy Outlook 2007*, DOE/EIA-0383(2007) (Washington, DC, February, 2007), Table 1, web site www.eia.doe.gov/oiaf/aeo; and *International Energy Outlook 2007*, DOE/EIA-0484(2007) (Washington, DC, May 2007), Table A10.

Greenhouse Gas Emissions Overview

Recent U.S. and International Developments in Global Climate Change

United States

- In December 2005, seven Northeastern and Mid-Atlantic States issued a Memorandum of Understanding to implement the Regional Greenhouse Gas Initiative (RGGI), a multi-State agreement that establishes a cap-and-trade system for carbon dioxide emissions from electric power plants.[1] RGGI aims to stabilize utilities' CO_2 emissions at current levels through 2015 and then reduce them by 10 percent by 2020. The first compliance period under RGGI begins January 1, 2009.[2] In 2007, three additional States joined RGGI: Massachusetts and Rhode Island in January and Maryland in April.
- On February 26, 2007, the Governors of Arizona, California, New Mexico, Oregon, and Washington signed an agreement establishing the Western Climate Initiative,[3] a joint effort to reduce greenhouse gas emissions and address climate change. Since then, Utah and the Canadian Provinces of Manitoba and British Columbia have joined the initiative as full partners. Five U.S. States, three Canadian Provinces, and one Mexican State are observers.[4] In August 2007, the partners released their regional greenhouse gas emissions reduction goal of 15 percent below 2005 levels by 2020.
- On April 2, 2007, the U.S. Supreme Court, in *Massachusetts v. the Environmental Protection Agency*, ruled that section 202(a)(1) of the Clean Air Act gives the U.S. Environmental Protection Agency authority to regulate tailpipe emissions of greenhouse gases.[5]
- On May 8, 2007, 31 U.S. States and one Tribal Nation signed on as charter members in the development of The Climate Registry (TCR), a voluntary, common system for entities to report greenhouse gas emissions.[6] Founding members also include those States, Provinces, and Nations that joined TCR before the May 25, 2007, press release announcing the program.[7] TCR will incorporate the California Climate Action Registry (CCAR), the Eastern Climate Registry, the Western Regional Air Partnership, and the Lake Michigan Air Directors Consortium (LADCO), making it the largest State- and Province-based effort to date to track greenhouse gas emissions.[8] States that previously had passed reporting and registry legislation plan to roll their programs into TCR. As of October 2007, 9 additional U.S. States and the District of Columbia, 1 Mexican State, and 2 additional Tribal Nations had joined the effort.[9]
- On May 14, 2007, President Bush issued a "Twenty in Ten" Executive Order, directing Federal agencies to write rules for expanding the alternative fuel mandate and boosting vehicle fuel efficiency standards. The rules are to be completed by December 2008.
- Also in May 2007, the Chicago Climate Exchange (CCX) announced the formation of a California Climate Exchange to develop and trade financial products with the aim of helping the State meet its mandatory emissions reductions goals.[10] In August 2007, Germany's foreign minister met with California Governor Arnold Schwarzenegger to promote integration of the European carbon market with the emissions trading scheme emerging in the western United States.[11]
- Washington State Governor Christine Gregoire signed Substitute Senate Bill 6001 (SSB 6001) in May 2007, imposing an emissions performance standard on

(continued on page 9)

[1]States participating in RGGI are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. The District of Columbia, Pennsylvania, the Eastern Canadian Provinces, and New Brunswick are observers in the process.

[2]See web site www.rggi.org.

[3]See web site http://westernclimateinitiative.org.

[4]Observers to the Western Climate Initiative are: Alaska, Colorado, Kansas, Nevada, Wyoming, the Canadian Provinces of Ontario, Quebec, and Saskatchewan and the Mexican State of Sonora.

[5]Supreme Court of the United States, "Massachusetts et al. v. Environmental Protection Agency et al." No. 05-1120, Argued 11/29/06, Decided 4/22/07. See web site www.supremecourtus.gov/opinions/06pdf/05-1120.pdf.

[6]The charter member States and Tribes include Arizona, California, Colorado, Connecticut, Delaware, Florida, Hawaii, Illinois, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, New Hampshire, New Jersey, New Mexico, New York, North Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, Utah, Vermont, Washington, Wisconsin, Wyoming, and the Campo Kumayaay Nation.

[7]Founding members include the charter members plus Alabama, Georgia, Virginia, Pueblo of Acoma and Southern Indian Tribes, British Columbia, and Manitoba.

[8]See web site www.theclimateregistry.org.

[9]Additional members as of October 2007 are Idaho, Iowa, Nevada, Oklahoma, Oregon, Tennessee, and the Mexican State of Sonora.

[10]"Chicago Climate Exchange to Form Carbon Trading Market in California," Point Carbon, web site www.pointcarbon.com/Home/News/All%20news/article22509-703.html (May 29, 2007).

[11]"Germany, California Discuss Cooperation on Carbon Markets," *Point Carbon*, web site www.pointcarbon.com/article.php?articleID=24257 (August 31, 2007).

Greenhouse Gas Emissions Overview

Recent U.S. and International Developments in Global Climate Change

United States

baseload electricity generation (similar to SB 1368 in California).[12] Oregon is considering adopting a similar emissions performance standard for long-term power purchase agreements. Also in May 2007, Montana adopted a carbon dioxide emissions performance standard for electric generating units in the State.[13] The State Public Utility Commission cannot approve generating units constructed after January 1, 2007, that are fueled primarily by coal unless a minimum of 50 percent of the carbon dioxide produced by the facilities is captured and sequestered.

- At the local level, as of September 2007, 681 mayors from the 50 States, the District of Columbia, and Puerto Rico had signed on to the Climate Protection Agreement. Originally adopted in June 2005,[14] the Agreement follows the Kyoto Protocol in setting a goal of reducing greenhouse gas emissions to 7 percent below 1990 levels by 2012.
- As of October 2007, 210 U.S. cities had joined more than 800 local governments across the world in the Cities for Climate Protection (CCP) initiative run by the International Council for Local Environmental Initiatives (ICLEI).[15] CCP assists cities in adopting policies and implementing quantifiable measures to reduce local greenhouse gas emissions, improve air quality, and enhance urban livability and sustainability.

International: United Nations Framework Convention on Climate Change and the Kyoto Protocol

COP-12 and COP/MOP-2

In November 2006, the Twelfth Conference of the Parties to the United Nation's Framework Convention on Climate Change (COP-12) and the Second Meeting of the Parties to the Kyoto Protocol (COP/MOP-2) were held in Nairobi, Kenya. Key areas included:

- Review of the implementation of the UNFCCC to inform the dialog on long-term mitigation measures (COP-12)
- Adverse effects of climate change on developing and least developed countries (COP-12)
- Financial mechanisms, national communications, technology transfer, and capacity building (COP-12)
- Long-term action on post-2012 targets under the Kyoto Protocol (COP/MOP-2)
- Russia's proposal on voluntary commitments for developing countries (COP/MOP-2)
- Review of effectiveness of commitments and implementation (COP/MOP-2)
- Increased geographic equity in the use of the Clean Development Mechanism (COP/MOP-2)
- First amendment to the Kyoto Protocol to include Belarus and Kazakhstan as Annex B countries with binding targets (COP/MOP-2).

COP-13 and CMP-3

Indonesia will host COP-13 and CMP-3 (shortened from COP/MOP) in Nusa Dua, Bali, December 3-14, 2007. Among the agenda items to be included:

- Implementation of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (COP-13)
- Financial mechanisms of the Convention (COP-13)
- National communications (COP-13)
- Development and transfer of technologies (COP-13)
- Capacity building under the Convention (COP-13)
- Implementation of the Buenos Aires program of work on adaption and response measures (COP-13)
- Reducing emissions from deforestation in developing countries (COP-13)
- Issues relating to the Clean Development Mechanism and Join Implementation (CMP-3)
- Report of the Compliance Committee and of the administrator of the Kyoto Protocol International Transaction Log (CMP-3)
- Proposal from Belarus to amend Annex B for its inclusion (CMP-3).

[12]U.S. Department of Energy, Energy Efficiency and Renewable Energy, "Washington State Passes Climate Change Legislation," web site www.eere.energy.gov/states/news_detail.cfm/news_id=10776 (May 7, 2007).

[13]Montana Governor Brian Schweitzer, Signing Statement, House Bill 25, web site http://governor.mt.gov/news/docs/HB25SigningStatement.pdf (May 14, 2007).

[14]"U.S. Conference of Mayors Climate Protection Agreement," web site www.usmayors.org/climateprotection/agreement.htm (July 13, 2007).

[15]ICLEI was founded in 1990 as the International Council for Local Environmental Initiatives, when more than 200 local governments from 43 countries convened at the inaugural World Congress of Local Governments for a Sustainable Future at the United Nations in New York City. ICLEI began with the idea that one municipality could have a measurable effect on a global scale, which led to the realization that the cumulative effect of cities working in partnership would be profound. At the congress, ICLEI was recognized as the international environmental agency for local governments. See web site www.iclei.org/index.php?id=800.

Greenhouse Gas Emissions Overview

Units for Measuring Greenhouse Gases

Emissions data are reported here in metric units, as favored by the international scientific community. Metric tons are relatively intuitive for users of English measurement units, because 1 metric ton is only about 10 percent heavier than 1 English short ton.

Throughout this report, emissions of carbon dioxide and other greenhouse gases are given in carbon dioxide equivalents. In the case of carbon dioxide, emissions denominated in the molecular weight of the gas or in carbon dioxide equivalents are the same. Carbon dioxide equivalent data can be converted to carbon equivalents by multiplying by 12/44.

Emissions of other greenhouse gases (such as methane) can also be measured in carbon dioxide equivalent units by multiplying their emissions (in metric tons) by their global warming potentials (GWPs). Carbon dioxide equivalents are the amount of carbon dioxide by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas.

Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured (for example, methane) by its estimated GWP (which is 23 for methane). In 2001, the Intergovernmental Panel on Climate Change (IPCC) Working Group I released its Third Assessment Report, *Climate Change 2001: The Scientific Basis*.[16] Among other things, the Third Assessment Report updated a number of the GWP estimates that appeared in the IPCC's Second Assessment Report.[17] The GWPs published in the Third Assessment Report were used for the calculation of carbon dioxide equivalent emissions for this report. Generally, the level of total U.S. carbon dioxide equivalent emissions is 0.6 percent higher when the GWPs from the Third Assessment Report are used; however, the trends in growth of greenhouse gas emissions are similar for the two sets of GWP values. GWPs from the Second Assessment Report still are used for comparisons among countries.

[16]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

[17]Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge, UK: Cambridge University Press, 1996).

Carbon Dioxide Emissions

Total Emissions

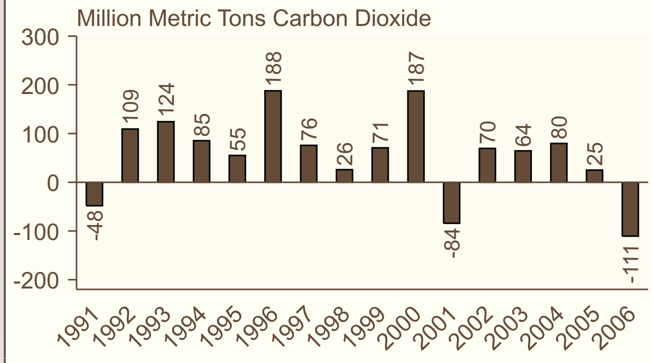
Summary

- The important factors that contributed to a drop in carbon dioxide emissions in 2006 (Figure 5) included: total energy consumption in 2006 that was 0.5 percent below the 2005 total—due in part to favorable weather conditions (both heating and cooling degree-days were below 2005 levels) and in part to higher energy prices that helped to dampen energy demand.
- A decline in the carbon intensity of electric power generation that resulted from increased use of natural gas, the least carbon-intensive fossil fuel, and greater reliance on non-fossil energy sources also contributed to the decrease.
- Relatively small increases in emissions from other sources of carbon dioxide, such as industrial processes, and from the U.S. Territories, which in total represent only a minor share of U.S. emissions, were not enough to offset the declines from major energy sources.
- Energy-related carbon dioxide, including emissions resulting from nonfuel uses of energy fuels (primarily petroleum) and adjustments for U.S. Territories and international bunker fuels, account for 98 percent of carbon dioxide emissions (Table 4).
- Emissions from other sources, such as industrial processes, account for 2 percent of carbon dioxide emissions.

U.S. Anthropogenic Carbon Dioxide Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	5,017.5	6,045.0	5,934.4
Change from 1990 (Million Metric Tons)		1,027.5	916.9
(Percent)		*20.5%*	*18.3%*
Average Annual Change from 1990 *(Percent)*		*1.2%*	*1.1%*
Change from 2005 (Million Metric Tons)			-110.6
(Percent)			*-1.8%*

Figure 5. Annual Change in U.S. Carbon Dioxide Emissions, 1990-2006



Source: EIA estimates.

Table 4. U.S. Carbon Dioxide Emissions from Energy and Industry, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide)

Fuel Type or Process	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Energy Consumption										
Petroleum	2,172.0	2,199.6	2,407.3	2,452.0	2,464.0	2,461.5	2,506.9	2,597.1	2,614.8	2,581.2
Coal	1,799.7	1,897.5	2,051.2	2,144.9	2,083.6	2,092.7	2,130.1	2,154.6	2,162.4	2,134.1
Natural Gas	1,033.6	1,193.0	1,199.2	1,239.8	1,190.3	1,245.7	1,216.7	1,194.1	1,192.8	1,163.1
Renewables[a]	6.3	10.5	10.9	10.6	11.2	13.1	11.8	11.5	11.6	11.9
Energy Subtotal	**5,011.6**	**5,300.6**	**5,668.6**	**5,847.2**	**5,749.1**	**5,813.0**	**5,865.5**	**5,957.4**	**5,981.6**	**5,890.3**
Nonfuel Use Emissions[b]	*98.8*	*105.5*	*125.0*	*110.8*	*105.8*	*106.2*	*104.2*	*112.1*	*107.3*	*111.5*
Nonfuel Use Sequestration[c]	*251.2*	*286.5*	*325.9*	*308.2*	*293.8*	*293.9*	*289.6*	*311.9*	*302.3*	*302.0*
Adjustments to Energy	-82.4	-62.4	-66.5	-59.0	-44.0	-36.4	-27.3	-42.8	-43.8	-64.8
Adjusted Energy Subtotal	**4,929.3**	**5,238.1**	**5,602.1**	**5,788.3**	**5,705.1**	**5,776.6**	**5,838.2**	**5,914.6**	**5,937.8**	**5,825.5**
Other Sources	88.2	105.2	101.1	102.2	101.2	99.3	102.2	105.3	107.1	108.8
Total	**5,017.5**	**5,343.4**	**5,703.1**	**5,890.5**	**5,806.3**	**5,875.9**	**5,940.4**	**6,019.9**	**6,045.0**	**5,934.4**

[a]Includes emissions from electricity generation using nonbiogenic municipal solid waste and geothermal energy.
[b]Emissions from nonfuel uses are included in the energy subtotal.
[c]Carbon sequestered by nonfuel uses is subtracted from the energy emissions subtotal.
P = preliminary data.
Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding. Adjusted energy subtotal includes U.S. Territories but excludes international bunker fuels.
Source: EIA estimates.

Carbon Dioxide Emissions

Residential Sector

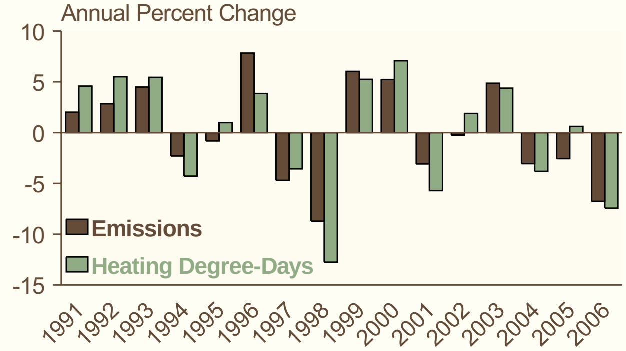
Summary

- Residential sector carbon dioxide emissions consist of:
  - Direct fuel consumption (principally natural gas) for heating and cooking
  - Electricity for cooling (and some heating), for lighting, and increasingly for televisions, computers, and other household electronic devices (Table 5).
- Weather dominates the year-to-year changes for residential energy demand and related emissions:
  - In 2006, heating degree-days declined by 7.4 percent (Figure 6), and cooling degree-days declined by almost 2 percent, from 2005 levels.
- In the longer run, residential emissions are affected by population growth and income. From 1990 to 2006:
  - U.S. population grew by an average of 1.2 percent per year
  - Residential sector carbon dioxide emissions grew by an average of 1.4 percent per year
  - Per capita income (measured in constant dollars) grew by an average of 1.8 percent per year.

Residential Sector Carbon Dioxide Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	961.6	1,253.0	1,204.2
Change from 1990 (Million Metric Tons)		291.3	242.6
(Percent)		*30.3%*	*25.2%*
Average Annual Change from 1990 *(Percent)*		*1.8%*	*1.4%*
Change from 2005 (Million Metric Tons)			-48.7
(Percent)			*-3.9%*

Figure 6. Annual Changes in U.S. Heating Degree-Days and Residential Sector CO_2 Emissions from Direct Fuel Combustion, 1990-2006



Source: EIA estimates.

Table 5. U.S. Carbon Dioxide Emissions from Residential Sector Energy Consumption, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Petroleum										
Liquefied Petroleum Gas	22.7	25.2	33.3	35.1	33.3	33.8	35.1	33.1	31.4	31.6
Distillate Fuel	71.6	66.2	60.6	66.2	66.4	62.9	66.2	67.6	62.5	63.6
Kerosene	4.6	5.4	8.0	6.8	6.9	4.3	5.1	6.1	6.6	5.1
Petroleum Subtotal	**98.9**	**96.7**	**101.8**	**108.1**	**106.7**	**101.0**	**106.4**	**106.8**	**100.5**	**100.3**
Coal	2.9	1.7	1.3	1.0	1.0	1.1	1.2	1.2	0.9	0.6
Natural Gas	239.8	264.4	257.7	270.6	260.3	265.0	277.5	263.7	261.6	237.3
Electricity[a]	620.0	676.3	759.2	801.8	803.0	829.1	839.1	849.8	890.0	866.0
Total	**961.6**	**1,039.2**	**1,120.0**	**1,181.5**	**1,171.1**	**1,196.2**	**1,224.1**	**1,221.5**	**1,253.0**	**1,204.2**

[a]Share of total electric power sector carbon dioxide emissions weighted by sales to the residential sector.
P = preliminary data.
Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Carbon Dioxide Emissions

Commercial Sector

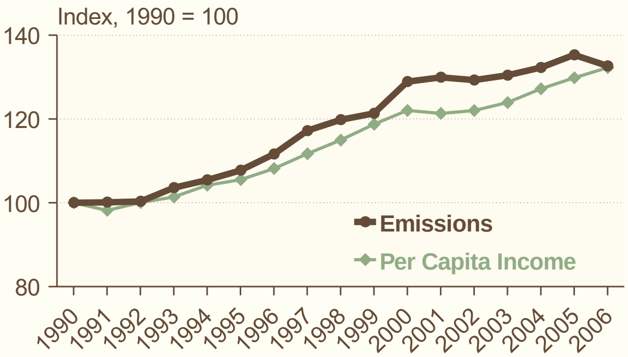
Summary

- Commercial sector emissions (Table 6) are largely the result of energy use for lighting, space heating, and space cooling in commercial structures, such as office buildings, shopping malls, schools, hospitals, and restaurants.
- Lighting accounts for a larger component of energy demand in the commercial sector (approximately 21 percent of total demand in 2005) than in the residential sector (approximately 11 percent of the total).
- Commercial sector emissions are affected less by weather than are residential sector emissions: heating and cooling accounted for approximately 40 percent of energy demand in the residential sector in 2005 but only about 22 percent in the commercial sector.[18]
- In the longer run, trends in emissions from the commercial sector parallel economic trends.
- Commercial sector emissions grew at an average annual rate of 1.8 percent from 1990 to 2006—the same rate as growth in real per capita income (Figure 7).

Commercial Sector Carbon Dioxide Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	787.5	1,065.4	1,045.2
Change from 1990 (Million Metric Tons)		277.8	257.7
(Percent)		*35.3%*	*32.7%*
Average Annual Change from 1990 *(Percent)*		*2.0%*	*1.8%*
Change from 2005 (Million Metric Tons)			-20.2
(Percent)			*-1.9%*

Figure 7. U.S. Commercial Sector CO_2 Emissions and Per Capita Income, 1990-2006



Source: EIA estimates.

Table 6. U.S. Carbon Dioxide Emissions from Commercial Sector Energy Consumption, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Petroleum										
Motor Gasoline	7.9	1.3	2.0	3.2	2.7	3.2	4.2	3.4	3.5	3.5
Liquefied Petroleum Gas	4.0	4.4	5.9	6.2	5.9	6.0	6.2	5.8	5.5	5.6
Distillate Fuel	39.2	35.0	32.1	35.9	37.2	32.5	35.2	34.4	32.7	33.3
Residual Fuel	18.1	11.1	5.8	7.2	5.5	6.3	8.8	9.7	9.1	8.9
Kerosene	0.9	1.6	1.9	2.1	2.3	1.2	1.3	1.5	1.6	1.2
Petroleum Subtotal	**70.1**	**53.5**	**47.7**	**54.6**	**53.5**	**49.1**	**55.8**	**54.8**	**52.5**	**52.6**
Coal	11.8	11.1	9.7	8.2	8.4	8.4	7.9	9.7	9.2	6.2
Natural Gas	143.1	165.4	166.2	172.7	165.1	171.0	174.7	169.6	168.8	154.6
Electricity[a]	562.5	618.4	731.9	779.6	796.2	789.5	788.7	807.4	834.9	831.9
Total	**787.5**	**848.4**	**955.5**	**1,015.1**	**1,023.3**	**1,018.1**	**1,027.1**	**1,041.6**	**1,065.4**	**1,045.2**

[a]Share of total electric power sector carbon dioxide emissions weighted by sales to the commercial sector.
P = preliminary data.
Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

[18]Energy Information Administration, *Annual Energy Outlook 2007*, DOE/EIA-0383(2006) (Washington, DC, February 2007), Table A5, web site www.eia.doe.gov/oiaf/aeo/excel/aeo_base.xls.

Carbon Dioxide Emissions

Industrial Sector

Summary

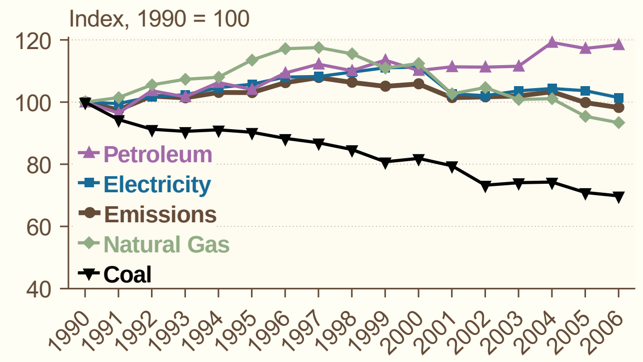
- Unlike commercial sector emissions, trends in U.S. industrial sector emissions (Table 7) have not followed the trends in economic growth.
- Decreases in industrial sector carbon dioxide emissions have resulted largely from erosion of the older energy-intensive (specifically coal-intensive) U.S. industrial base.
- Coke plants consumed 23.0 million short tons of coal in 2006, down from 38.9 million short tons in 1990.
- Other industrial coal consumption declined from 76.3 million short tons in 1990 to 60.5 million short tons in 2006.
- Total industrial coal use dropped by more than 27 percent from 1990 to 2006 (Figure 8).
- The share of manufacturing activity represented by less energy-intensive industries, such as computer chip and electronic component manufacturing, has increased, while the share represented by the more energy-intensive industries has fallen.

Industrial Sector Carbon Dioxide Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	1,679.9	1,677.1	1,650.8
Change from 1990 (Million Metric Tons)		-2.8	-29.1
(Percent)		*0.2%*	*-1.7%*
Average Annual Change from 1990 *(Percent)*		*	*-0.1%*
Change from 2005 (Million Metric Tons)			-26.3
(Percent)			*-1.6%*

*Less than 0.05 percent.

Figure 8. U.S. Industrial Sector CO_2 Emissions and Major Industrial Fuel Use, 1990-2006



Source: EIA estimates.

Table 7. U.S. Carbon Dioxide Emissions from Industrial Sector Energy Consumption, 1990, 1996, and 1999-2006
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Petroleum										
Motor Gasoline	13.2	14.2	10.8	10.7	20.9	21.9	23.0	26.4	26.5	26.7
Liquefied Petroleum Gas	40.1	46.6	49.6	58.2	50.4	56.1	51.7	57.1	54.7	54.1
Distillate Fuel	83.9	82.4	86.4	87.4	94.7	87.7	82.7	88.4	92.0	93.4
Residual Fuel	30.6	24.5	14.1	16.7	13.8	13.2	15.6	17.9	20.4	20.3
Asphalt and Road Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lubricants	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kerosene	0.9	1.1	0.9	1.1	1.7	1.0	1.7	2.0	2.2	1.7
Petroleum Coke	63.8	66.9	81.1	74.1	77.0	76.2	76.0	82.8	79.1	81.9
Other Petroleum	125.4	112.5	128.4	115.9	130.3	127.6	137.7	140.3	137.5	143.3
Petroleum Subtotal	**358.0**	**348.2**	**371.2**	**364.1**	**388.7**	**383.7**	**388.4**	**414.9**	**412.4**	**421.4**
Coal	**250.3**	**225.9**	**208.0**	**214.1**	**215.3**	**205.2**	**205.8**	**208.1**	**184.6**	**183.8**
Coal Coke Net Imports	**0.5**	**5.7**	**6.6**	**6.1**	**2.7**	**5.7**	**4.7**	**12.9**	**4.1**	**5.7**
Natural Gas	**436.7**	**494.0**	**477.3**	**478.1**	**438.9**	**464.5**	**447.4**	**430.8**	**408.7**	**399.2**
Electricity[a]	**634.5**	**657.0**	**701.8**	**715.6**	**658.2**	**648.7**	**666.4**	**669.1**	**667.3**	**640.7**
Total[b]	**1,679.9**	**1,730.9**	**1,764.8**	**1,778.1**	**1,703.8**	**1,707.8**	**1,712.8**	**1,735.7**	**1,677.1**	**1,650.8**

[a]Share of total electric power sector carbon dioxide emissions weighted by sales to the industrial sector.
[b]Includes emissions from nonfuel uses of fossil fuels. See Table 10 for details by fuel category.
P = preliminary data.
Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Carbon Dioxide Emissions

Transportation Sector

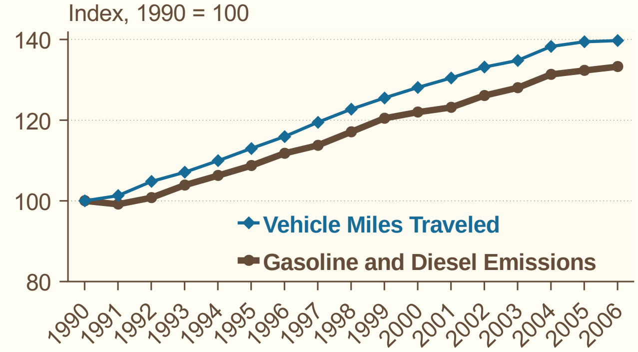
Summary

- Transportation sector carbon dioxide emissions in 2006 were 407.5 million metric tons higher than in 1990 (Table 8), an increase that represents 46.4 percent of the growth in unadjusted energy-related carbon dioxide emissions from all sectors over the period.
- Since 1999, the transportation sector has led all U.S. end-use sectors in emissions of carbon dioxide.
- Petroleum combustion is the largest source of carbon dioxide emissions in the transportation sector, as opposed to electricity-related emissions in the other end-use sectors.
- Increases in ethanol fuel consumption in recent years have mitigated the growth in transportation sector emissions somewhat (emissions from energy inputs to ethanol production plants are counted in the industrial sector).
- Transportation sector emissions from gasoline and diesel fuel combustion generally parallel total vehicle miles traveled (Figure 9).

Transportation Sector Carbon Dioxide Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	1,582.6	1,986.2	1,990.1
Change from 1990 (Million Metric Tons)		403.6	407.5
(Percent)		*25.5%*	*25.8%*
Average Annual Change from 1990 *(Percent)*		*1.5%*	*1.4%*
Change from 2005 (Million Metric Tons)			3.9
(Percent)			*0.2%*

Figure 9. U.S. Vehicle Miles Traveled and CO_2 Emissions from Gasoline and Diesel Transportation Fuel Use, 1990-2006



Source: EIA estimates.

Table 8. U.S. Carbon Dioxide Emissions from Transportation Sector Energy Consumption, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Petroleum										
Motor Gasoline	961.7	1,029.7	1,115.1	1,121.9	1,127.1	1,155.8	1,159.5	1,180.8	1,182.2	1,186.2
Liquefied Petroleum Gas	1.3	1.0	0.8	0.7	0.8	0.8	1.0	1.1	1.1	1.1
Jet Fuel	222.6	222.1	245.4	253.8	242.8	236.8	231.5	239.8	246.3	239.5
Distillate Fuel	267.8	306.9	365.8	377.8	387.1	394.5	414.5	433.9	444.4	452.2
Residual Fuel	80.1	71.7	52.4	69.9	46.1	53.3	45.0	58.3	66.0	65.6
Lubricants[a]	6.5	6.2	6.8	6.7	6.1	6.0	5.6	5.6	5.6	5.5
Aviation Gasoline	3.1	2.7	2.7	2.5	2.4	2.3	2.1	2.2	2.4	2.3
Petroleum Subtotal	**1,543.2**	**1,640.4**	**1,789.1**	**1,833.3**	**1,812.5**	**1,849.5**	**1,859.1**	**1,921.7**	**1,948.1**	**1,952.4**
Coal	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Natural Gas	**36.2**	**38.6**	**35.8**	**35.6**	**34.8**	**37.7**	**37.8**	**32.2**	**33.2**	**32.5**
Electricity[b]	**3.2**	**3.2**	**3.4**	**3.6**	**3.7**	**3.6**	**4.6**	**4.7**	**4.9**	**5.2**
Total	**1,582.6**	**1,682.2**	**1,828.3**	**1,872.6**	**1,851.0**	**1,890.9**	**1,901.4**	**1,958.6**	**1,986.2**	**1,990.1**

[a]Includes emissions from nonfuel uses of fossil fuels. See Table 10 for details by fuel category.
[b]Share of total electric power sector carbon dioxide emissions weighted by sales to the transportation sector.
P = preliminary data.
Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Carbon Dioxide Emissions

Electric Power Sector

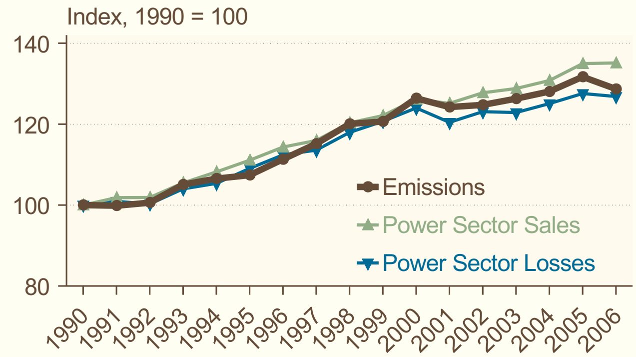
Summary

- The electric power sector transforms primary energy inputs into electricity. The sector consists of companies whose primary business is the generation of electricity.
- From 2005 to 2006, electricity demand was essentially flat and the carbon intensity of the electricity supply fell, leading to a drop in electric power sector emissions (Table 9).
- From 2000 to 2006, as the overall efficiency of U.S. electricity generation has increased, there has been a decline in electric power sector energy losses[19] relative to total sales, which has helped to mitigate the sector's carbon dioxide emissions (Figure 10).
- From year to year, demand for electricity can be affected by the number of cooling degree-days.
- All the end-use sectors except transportation have increasingly relied on electricity as an energy source, displacing other fuels.
- Carbon dioxide emissions from electricity generation in the commercial and industrial sectors are counted in those sectors.

Electric Power Sector Carbon Dioxide Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	1,820.2	2,397.1	2,343.9
Change from 1990			
(Million Metric Tons)		576.9	523.7
(Percent)		31.7%	28.8%
Average Annual Change from 1990 (Percent)		1.9%	1.6%
Change from 2005			
(Million Metric Tons)			-53.3
(Percent)			-2.2%

Figure 10. U.S. Electric Power Sector Energy Sales and Losses and CO_2 Emissions from Primary Fuel Combustion, 1990-2006



Source: EIA estimates.

Table 9. U.S. Carbon Dioxide Emissions from Electric Power Sector Energy Consumption, 1990, 1995, and 1999-2006 (Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Petroleum										
Residual Fuel	91.9	45.0	76.5	69.5	80.1	52.3	69.0	69.8	69.8	28.7
Distillate Fuel	7.1	7.9	10.2	12.8	12.5	9.3	11.7	8.1	8.4	5.4
Petroleum Coke	2.9	7.8	10.8	9.6	10.1	16.6	16.5	21.1	23.2	20.5
Petroleum Subtotal	101.9	60.7	97.5	91.8	102.6	78.2	97.2	99.0	101.3	54.5
Coal	1,534.2	1,653.2	1,825.6	1,915.5	1,856.1	1,872.2	1,910.5	1,922.7	1,963.7	1,937.9
Natural Gas	177.7	230.6	262.2	282.8	291.1	307.4	279.3	297.7	320.5	339.5
Municipal Solid Waste	5.9	10.1	10.5	10.2	10.9	12.7	11.4	11.2	11.2	11.5
Geothermal	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4
Total	1,820.2	1,955.0	2,196.3	2,300.7	2,261.1	2,270.9	2,298.8	2,331.0	2,397.1	2,343.9

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, Emissions of Greenhouse Gases in the United States 2005, DOE/EIA-0573(2005) (Washington, DC, November 2006). Emissions for total fuel consumption are allocated to end-use sectors in proportion to electricity sales. Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

[19]Electrical system energy losses are calculated as the difference between total primary consumption by the electric power sector and the total energy content of retail electricity sales.

Carbon Dioxide Emissions

Nonfuel Uses of Energy Inputs

Summary

- The use of fossil fuels for purposes other than the energy value of the fuel creates emissions and also sequesters carbon in nonfuel products. Both the emissions and sequestration are included in the total for energy-related carbon dioxide emissions:
  - In 2006, carbon dioxide emissions from nonfuel uses of energy inputs totaled 111.5 MMT—almost 4 percent above the 2005 total (Table 10).
  - Carbon sequestration from nonfuel uses of energy inputs in 2006 included 302 $MMTCO_2e$ that was embedded in plastics and other nonfuel products rather than emitted to the atmosphere (see Table 11 on page 18).
  - The 2006 sequestration total was about the same as the 2005 total.

Carbon Dioxide Emissions from Nonfuel Uses of Energy Inputs, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	98.8	107.3	111.5
Change from 1990 (Million Metric Tons)		8.4	12.7
(Percent)		*8.5%*	*12.8%*
Average Annual Change from 1990 *(Percent)*		*0.5%*	*0.8%*
Change from 2005 (Million Metric Tons)			4.2
(Percent)			*3.9%*

Carbon Sequestration from Nonfuel Uses of Energy Inputs, 1990, 2005, and 2006

	1990	2005	2006
Estimated Sequestration (Million Metric Tons CO_2e)	251.2	302.3	302.0
Change from 1990 (Million Metric Tons CO_2e)		51.1	50.8
(Percent)		*20.3%*	*20.2%*
Average Annual Change from 1990 *(Percent)*		*1.2%*	*1.2%*
Change from 2005 (Million Metric Tons CO_2e)			-0.3
(Percent)			*-0.1%*

Table 10. U.S. Carbon Dioxide Emissions from Nonfuel Use of Energy Fuels, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide)

End Use and Type	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Industrial										
Petroleum										
Liquefied Petroleum Gases	14.8	19.6	22.5	20.5	19.2	20.0	19.1	19.4	18.3	18.7
Distillate Fuel	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Residual Fuel	1.9	2.1	2.2	2.2	2.2	1.7	1.7	1.7	1.7	1.7
Asphalt and Road Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lubricants	6.9	6.6	7.2	7.0	6.5	6.4	5.9	6.0	5.9	5.8
Other *(Subtotal)*	*51.6*	*52.0*	*66.8*	*54.2*	*51.9*	*53.1*	*52.9*	*60.3*	*56.6*	*60.8*
Pentanes Plus	1.1	4.1	3.5	3.2	2.7	2.3	2.3	2.3	2.0	1.4
Petrochemical Feed	33.6	36.0	38.2	36.8	32.9	33.5	36.5	41.8	38.4	41.0
Petroleum Coke	9.1	6.8	14.5	7.2	10.6	9.8	8.2	12.6	11.7	13.3
Special Naphtha	7.8	5.2	10.6	7.1	5.7	7.5	5.9	3.7	4.6	5.1
Waxes and Miscellaneous	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum Subtotal	*75.5*	*80.6*	*99.1*	*84.5*	*80.2*	*81.6*	*80.0*	*87.9*	*83.1*	*87.5*
Coal	0.5	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
Natural Gas	16.3	18.0	18.6	19.1	18.9	18.1	18.1	18.1	18.1	18.1
Industrial Subtotal	**92.3**	**99.2**	**118.2**	**104.2**	**99.7**	**100.2**	**98.6**	**106.5**	**101.6**	**106.0**
Transportation										
Lubricants	6.5	6.2	6.8	6.7	6.1	6.0	5.6	5.6	5.6	5.5
Total	**98.8**	**105.5**	**125.0**	**110.8**	**105.8**	**106.2**	**104.2**	**112.1**	**107.3**	**111.5**

P = preliminary data.

Notes: Emissions from nonfuel use of energy fuels are included in the energy consumption tables in this chapter. Data in this table are revised from unpublished data used to produce the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates.

Carbon Dioxide Emissions

Nonfuel Uses of Energy Inputs

Table 11. U.S. Carbon Sequestered by Nonfuel Use of Energy Fuels, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

End Use and Type	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Industrial										
Petroleum										
Liquefied Petroleum Gases. . .	59.3	78.5	89.9	82.1	76.7	79.9	76.3	77.7	73.4	74.7
Distillate Fuel	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Residual Fuel	1.9	2.1	2.2	2.2	2.2	1.7	1.7	1.7	1.7	1.7
Asphalt and Road Oil	88.5	89.1	100.1	96.4	95.0	93.7	92.2	98.6	100.0	95.3
Lubricants	6.9	6.6	7.2	7.0	6.5	6.4	5.9	6.0	5.9	5.8
Other *(Subtotal)*	*72.1*	*83.1*	*95.0*	*88.8*	*84.0*	*86.5*	*88.1*	*101.5*	*94.6*	*97.8*
Pentanes Plus.	4.4	16.2	14.0	12.7	10.8	9.2	9.0	9.1	8.0	5.7
Petrochemical Feed	46.0	50.0	55.5	57.7	50.7	55.1	59.2	69.2	64.2	66.7
Petroleum Coke	9.1	6.8	14.5	7.2	10.6	9.8	8.2	12.6	11.7	13.3
Special Naphtha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Waxes and Miscellaneous . .	12.6	10.2	11.0	11.2	11.9	12.3	11.6	10.7	10.7	12.0
Petroleum Subtotal	*228.9*	*259.7*	*294.9*	*277.0*	*264.8*	*268.7*	*264.7*	*286.0*	*276.2*	*275.7*
Coal.	1.4	2.1	1.8	1.8	1.7	1.5	1.5	1.5	1.5	1.4
Natural Gas.	14.3	18.4	22.5	22.6	21.2	17.7	17.9	18.9	19.0	19.4
Industrial Subtotal	**244.7**	**280.2**	**319.1**	**301.5**	**287.7**	**287.8**	**284.1**	**306.3**	**296.7**	**296.5**
Transportation										
Lubricants	6.5	6.2	6.8	6.7	6.1	6.0	5.6	5.6	5.6	5.5
Total	**251.2**	**286.5**	**325.9**	**308.2**	**293.8**	**293.9**	**289.6**	**311.9**	**302.3**	**302.0**

P = preliminary data.

Notes: Emissions from nonfuel use of energy fuels are included in the energy consumption tables in this chapter. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates.

Carbon Dioxide Emissions

Adjustments to Energy Consumption

Summary

- EIA's greenhouse gas emissions inventory includes two "adjustments to energy consumption" (Table 12):
  - Carbon dioxide emissions data in this report and the energy consumption data upon which they are based correspond to EIA's coverage of energy consumption, which includes the 50 States and the District of Columbia. Under the UNFCCC, however, the United States is also responsible for counting emissions emanating from its Territories. Therefore, their emissions are added to the U.S. total.
  - Because the definition of energy consumption by the IPCC excludes international bunker fuels from the statistics of all countries, emissions from international bunker fuels are subtracted from the U.S. total. Similarly, because the IPCC excludes emissions from military bunker fuels from national totals, they are subtracted from the U.S. total.

Carbon Dioxide Emissions from U.S. Territories, 1990, 2005, and 2006*

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	31.1	59.5	61.3
Change from 1990 (Million Metric Tons)		28.4	30.2
(Percent)		*91.3%*	*97.2%*
Average Annual Change from 1990 *(Percent)*		*4.4%*	*4.3%*
Change from 2005 (Million Metric Tons)			1.8
(Percent)			*3.1%*

*Added to total U.S. emissions.

Carbon Dioxide Emissions from International Bunker Fuels, 1990, 2005, and 2006*

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	113.5	103.3	126.1
Change from 1990 (Million Metric Tons)		-10.2	12.7
(Percent)		*-9.0%*	*11.2%*
Average Annual Change from 1990 *(Percent)*		*-0.6%*	*0.7%*
Change from 2005 (Million Metric Tons)			22.9
(Percent)			*22.1%*

*Subtracted from total U.S. emissions.

Table 12. U.S. Carbon Dioxide Emissions: Adjustments for U.S. Territories and International Bunker Fuels, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Emissions from U.S. Territories										
Puerto Rico	20.2	24.1	26.2	27.6	34.3	34.9	37.2	37.9	39.0	40.4
U.S. Virgin Islands	7.0	8.5	8.8	9.8	14.2	13.7	15.2	18.1	16.1	16.4
American Samoa	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Guam	1.8	3.6	3.4	2.9	3.1	2.1	2.4	2.0	2.2	2.3
U.S. Pacific Islands	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Wake Island	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4
Subtotal[a]	**31.1**	**38.4**	**40.6**	**42.4**	**53.8**	**52.9**	**57.0**	**60.1**	**59.5**	**61.3**
Emissions from Bunker Fuels										
Marine Bunkers *(Subtotal)*	*62.0*	*46.6*	*41.3*	*37.6*	*35.3*	*24.2*	*19.8*	*29.3*	*29.5*	*49.8*
Distillate Fuel	6.2	5.8	3.1	2.9	2.0	1.6	1.4	1.7	2.4	3.1
Residual Fuel	55.8	40.8	38.2	34.6	33.2	22.6	18.3	27.6	27.1	46.7
Aviation Bunkers *(Subtotal)*	*38.1*	*45.3*	*56.1*	*55.9*	*54.3*	*57.0*	*55.3*	*63.5*	*66.1*	*68.7*
U.S. Carriers	18.5	21.0	24.8	25.9	24.8	23.6	23.2	26.5	28.3	28.5
Foreign Carriers	19.5	24.3	31.3	30.0	29.5	33.3	32.1	37.0	37.9	40.2
Military Bunkers *(Subtotal)*	*13.4*	*8.9*	*9.8*	*7.9*	*8.2*	*8.1*	*9.2*	*10.1*	*7.6*	*7.6*
Subtotal[b]	**113.5**	**100.8**	**107.2**	**101.4**	**97.8**	**89.3**	**84.2**	**102.8**	**103.3**	**126.1**
Net Adjustment	**-82.4**	**-62.4**	**-66.5**	**-59.0**	**-44.0**	**-36.4**	**-27.3**	**-42.8**	**-43.8**	**-64.8**

P = preliminary data.
[a]Added to total U.S. emissions.
[b]Subtracted from total U.S. emissions.
Note: Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Carbon Dioxide Emissions

Other Sources

Summary

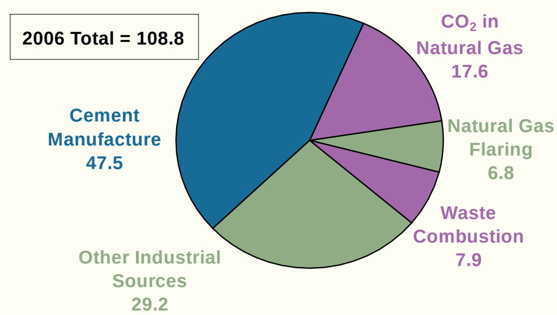
- "Other emissions sources" in total accounted for 1.8 percent (108.8 MMT) of all U.S. carbon dioxide emissions in 2006 (Figure 11).
- The largest source of U.S. carbon dioxide emissions other than fossil fuel consumption is cement manufacture (Table 13), where most emissions result from the production of clinker (consisting of calcium carbonate sintered with silica in a cement kiln to produce calcium silicate).
- Limestone consumption, especially for lime manufacture, is the source of 15 to 20 million metric tons of carbon dioxide emissions per year.
- In addition, "other sources" include: soda ash manufacture and consumption; carbon dioxide manufacture; aluminum manufacture; flaring of natural gas at the wellhead; carbon dioxide scrubbed from natural gas; and waste combustion.

Carbon Dioxide Emissions from Other Sources, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons)	88.2	107.1	108.8
Change from 1990 (Million Metric Tons)		18.9	20.6
(Percent)		*21.4%*	*23.3%*
Average Annual Change from 1990 *(Percent)*		*1.3%*	*1.3%*
Change from 2005 (Million Metric Tons)			1.7
(Percent)			*1.6%*

Figure 11. U.S. Carbon Dioxide Emissions from Other Sources, 2006

(Million Metric Tons)



Source: EIA estimates.

Table 13. U.S. Carbon Dioxide Emissions from Other Sources, 1990, 1995, and 1999-2006

(Million Metric Tons Carbon Dioxide)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Cement Manufacture	***33.3***	***36.9***	***40.1***	***41.3***	***41.5***	***43.0***	***43.2***	***45.7***	***46.1***	***47.5***
Clinker Production	32.6	36.1	39.2	40.4	40.5	42.0	42.2	44.7	45.1	46.4
Masonry Cement	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cement Kiln Dust	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9
Limestone Consumption	***15.9***	***17.8***	***18.3***	***18.6***	***18.1***	***17.0***	***18.0***	***18.9***	***18.9***	***19.7***
Lime Manufacture	12.4	14.5	15.5	15.4	14.8	14.1	15.1	15.7	15.7	16.5
Iron Smelting	1.7	1.2	1.0	1.1	1.0	0.9	0.9	1.0	0.8	0.9
Steelmaking	0.3	0.5	0.3	0.5	0.6	0.5	0.4	0.4	0.4	0.4
Copper Refining	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Glass Manufacture	0.1	0.3	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2
Flue Gas Desulfurization	0.7	0.9	1.1	1.2	1.4	1.3	1.3	1.4	1.5	1.5
Dolomite Manufacture	0.5	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Other										
Soda Ash Manufacture	3.4	3.8	3.7	3.6	3.6	3.5	3.6	3.8	3.9	3.9
Soda Ash Consumption	0.5	0.8	0.6	0.6	0.5	0.4	0.6	0.6	0.6	0.6
Carbon Dioxide Manufacture	0.9	1.0	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.6
Aluminum Manufacture	5.9	4.9	5.5	5.4	3.9	4.0	4.0	3.7	3.6	3.4
Shale Oil Production	0.2	*	*	*	*	*	*	*	*	*
Natural Gas Flaring	9.1	17.2	6.7	5.5	5.9	6.0	5.9	5.8	7.2	6.8
Carbon Dioxide in Natural Gas	14.0	16.7	17.8	18.2	18.6	17.9	18.1	17.6	17.1	17.6
Waste Combustion	5.0	6.1	7.1	7.8	7.9	6.1	7.4	7.6	8.2	7.9
Total	**88.2**	**105.2**	**101.1**	**102.2**	**101.2**	**99.3**	**102.2**	**105.3**	**107.1**	**108.8**

P = preliminary data.
*Less than 0.05 million metric tons.
Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Methane Emissions

Total Emissions

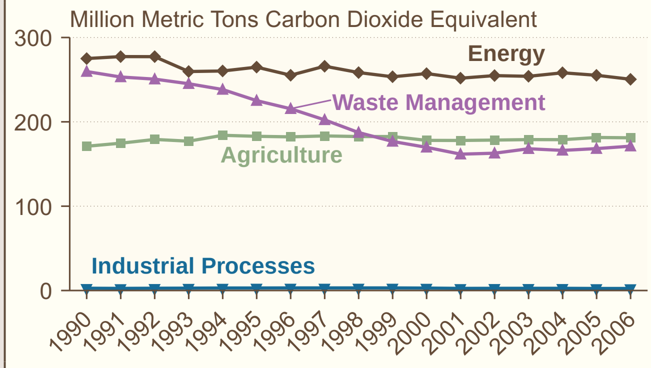
Summary

- The major sources of U.S. methane emissions are energy production, distribution, and use; agriculture; and waste management (Figure 12).
- U.S. methane emissions in 2006 totaled 605 million metric tons carbon dioxide equivalent ($MMTCO_2e$), down slightly from the 2005 total (Table 14).
- Methane emissions declined steadily from 1990 to 2001, as emissions from energy sources and waste management fell.
- Emissions rose from 2001 to 2005, as emissions from waste management increased in every year except 2004.
- The energy sector—including coal mining, natural gas systems, petroleum systems, and stationary and mobile combustion—is the largest source of U.S. methane emissions.
- Agriculture (primarily livestock management) and waste management (primarily landfills) also are large contributors to U.S. methane emissions.
- This is the first annual EIA emissions inventory that directly incorporates estimates of methane emissions from industrial wastewater treatment in the waste management category.

U.S. Anthropogenic Methane Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	708.4	607.3	605.1
Change from 1990 (Million Metric Tons CO_2e)		-101.0	-103.3
(Percent)		*-14.3%*	*-14.6%*
Average Annual Change from 1990 *(Percent)*		*-1.0%*	*-1.0%*
Change from 2005 (Million Metric Tons CO_2e)			-2.3
(Percent)			*-0.4%*

Figure 12. U.S. Methane Emissions by Source, 1990-2006



Source: EIA estimates.

Table 14. U.S. Methane Emissions from Anthropogenic Sources, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Energy Sources	275.0	264.8	253.4	257.2	251.8	254.8	254.0	258.2	255.1	250.4
Agricultural Sources	171.1	182.9	182.5	178.1	177.9	178.4	178.9	178.9	181.5	181.1
Waste Management	259.6	225.1	176.8	169.8	161.7	162.8	168.1	166.2	168.3	171.2
Industrial Processes	2.7	3.0	3.1	2.9	2.6	2.7	2.6	2.6	2.5	2.4
Total	**708.4**	**675.9**	**615.8**	**608.0**	**593.9**	**598.6**	**603.7**	**605.9**	**607.3**	**605.1**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2005*. Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), web site www.ipcc-nggip.iges.or.jp/public/public.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Methane Emissions

Energy Use

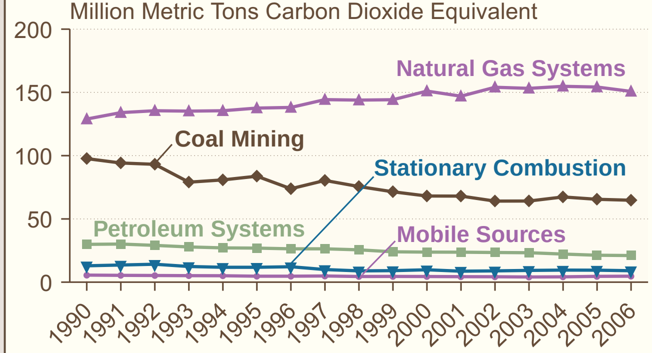
Summary

- Natural gas systems and coal mines are the major sources of methane emissions in the energy sector.
- Methane emissions from natural gas systems grew between 1990 and 2000, in parallel with increases in U.S. natural gas consumption, then leveled off from 2000 to 2006 (Figure 13 and Table 15).
- Emissions from coal mines declined from 1990 to 2002 and have remained low since then, because production increases have been largely from surface mines that produce relatively little methane.
- Methane emissions from petroleum systems have declined as domestic oil production has dropped by more than 30 percent since 1990.
- Residential wood consumption accounts for almost 90 percent of methane emissions from stationary combustion.
- Methane emissions from passenger cars, which declined from 1990 to 2003 as more efficient catalytic converters were added on newer models, have rebounded with increases in total vehicle miles traveled.

Energy-Related Methane Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	275.0	255.1	250.4
Change from 1990 (Million Metric Tons CO_2e)		-19.9	-24.6
(Percent)		*-7.2%*	*-8.9%*
Average Annual Change from 1990 *(Percent)*		*-0.5%*	*-0.6%*
Change from 2005 (Million Metric Tons CO_2e)			-4.7
(Percent)			*-1.8%*

Figure 13. U.S. Methane Emissions from Energy Sources, 1990-2006



Source: EIA estimates.

Table 15. U.S. Methane Emissions from Energy Sources, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Natural Gas Systems	***128.9***	***137.6***	***144.2***	***151.0***	***147.0***	***154.0***	***153.2***	***154.8***	***154.2***	***150.8***
Production	33.8	36.1	37.3	39.9	42.0	42.4	42.9	43.6	44.3	43.3
Processing	14.9	16.5	16.1	16.4	16.0	15.5	14.4	14.8	14.6	14.6
Transmission and Storage	48.3	49.3	52.8	55.4	49.0	55.6	54.7	53.7	53.5	51.0
Distribution	32.0	35.7	38.0	39.3	40.0	40.5	41.2	42.6	41.8	41.8
Coal Mining	***97.7***	***83.8***	***71.5***	***68.1***	***68.0***	***64.1***	***64.2***	***67.3***	***65.5***	***64.7***
Surface	10.7	11.2	12.5	12.4	13.2	13.0	12.7	13.1	13.5	14.2
Underground	87.0	72.5	58.9	55.7	54.9	51.1	51.5	54.2	52.1	50.5
Petroleum Systems	***29.9***	***26.9***	***24.0***	***23.8***	***23.7***	***23.5***	***23.3***	***22.3***	***21.3***	***21.1***
Refineries	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
Exploration and Production	29.0	26.1	23.2	22.9	22.9	22.6	22.4	21.4	20.4	20.3
Crude Oil Transportation	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Stationary Combustion	***12.9***	***11.8***	***9.1***	***9.8***	***8.7***	***8.9***	***9.3***	***9.5***	***9.5***	***9.1***
Mobile Sources	***5.6***	***4.7***	***4.6***	***4.5***	***4.3***	***4.3***	***4.1***	***4.2***	***4.6***	***4.8***
Total	**275.0**	**264.8**	**253.4**	**257.2**	**251.8**	**254.8**	**254.0**	**258.2**	**255.1**	**250.4**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2005.* Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), web site www.ipcc-nggip.iges.or.jp/public/public.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Methane Emissions

Agriculture

Summary

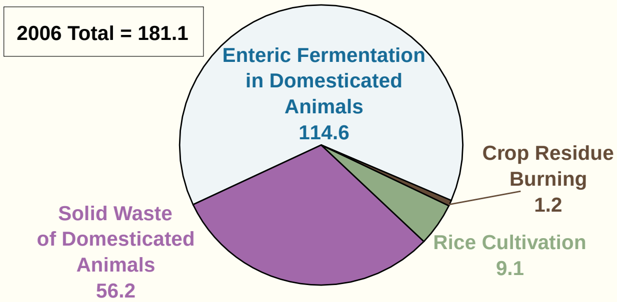
- Livestock management—including emissions from enteric fermentation (two-thirds) and management of animal wastes (one-third)—accounts for most of the U.S. methane emissions from agricultural activities (Table 16).
- Since 1990, there has been a shift in livestock management to larger facilities that are more likely to manage waste in liquid systems, which increase the amounts of methane generated from livestock waste.
- Because 95 percent of all methane emissions from enteric fermentation (digestion in ruminant animals) are attributable to cattle, trends in emissions are correlated with trends in the size of the U.S. cattle population.
- Decreases in U.S. rice production—particularly in Louisiana, Mississippi, and Arkansas—have reduced the estimated emissions from rice cultivation.
- Crop residue burning remains the smallest contributor to methane emissions from agriculture, representing less than 1 percent of total U.S. methane emissions (Figure 14).

Methane Emissions from Agricultural Sources, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	171.1	181.5	181.1
Change from 1990 (Million Metric Tons CO_2e)		10.4	10.0
(Percent)		*6.1%*	*5.8%*
Average Annual Change from 1990 *(Percent)*		*0.4%*	*0.4%*
Change from 2005 (Million Metric Tons CO_2e)			-0.4
(Percent)			*-0.2%*

Figure 14. U.S. Methane Emissions from Agriculture by Source, 2006

(Million Metric Tons Carbon Dioxide Equivalent)



Source: EIA estimates.

Table 16. U.S. Methane Emissions from Agricultural Sources, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Enteric Fermentation in Domesticated Animals	117.3	121.8	117.3	113.9	112.7	113.4	113.8	112.0	113.9	114.6
Solid Waste of Domesticated Animals	43.5	49.9	52.7	52.8	53.3	53.7	54.2	54.7	55.5	56.2
Rice Cultivation	9.3	10.2	11.5	10.2	10.7	10.2	9.8	10.9	10.9	9.1
Crop Residue Burning	1.0	1.0	1.1	1.1	1.1	1.0	1.2	1.3	1.2	1.2
Total	**171.1**	**182.9**	**182.5**	**178.1**	**177.9**	**178.4**	**178.9**	**178.9**	**181.5**	**181.1**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2005*. Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), web site www.ipcc-nggip.iges.or.jp/public/public.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Methane Emissions

Waste Management

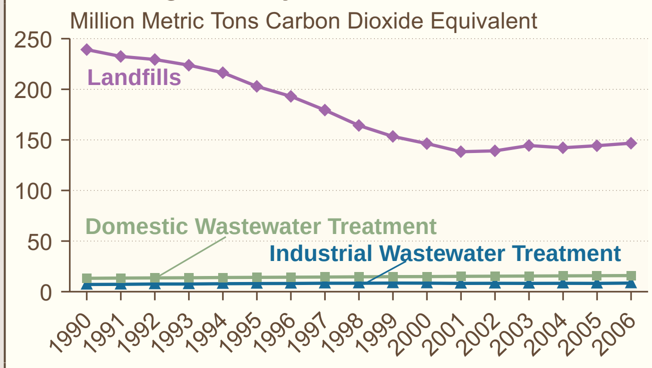
Summary

- Decomposition of solid waste in municipal and industrial landfills is the largest source of U.S. methane emissions from waste management (Table 17).
- Emissions from landfills declined substantially from 1990 to 2001 as a result of increases in recycling and in the recovery of landfill methane for energy; since 2001, annual increases in the total amount of waste deposited in landfills have resulted in increasing methane emissions (Figure 15).
- Rapid growth in methane recovery during the 1990s can be traced in part to the Federal Section 29 tax credit for alternative energy sources, which provided a subsidy of approximately 1 cent per kilowatthour for electricity generated from landfill gas before June 1998.
- Methane recovery may also have been increased by the U.S. EPA's New Source Performance Standards and Emission Guidelines, which require large landfills to collect and burn landfill gas.
- As part of the American Jobs Creation Act of 2004, a tax credit for electricity generation from landfill gas was added to Section 45 of the Internal Revenue Code. The credit was augmented under the Energy Policy Act of 2005, providing a 10-year tax credit valued at 0.9 cents per kilowatthour for landfill gas-to-energy projects placed in service between October 22, 2004, and December 31, 2007.
- About 14 percent of methane emissions from waste management are attributable to wastewater treatment, including both domestic wastewater (two-thirds) and industrial wastewater (one-third).

Methane Emissions from Waste Management, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	259.6	168.3	171.2
Change from 1990 (Million Metric Tons CO_2e)		-91.4	-88.4
(Percent)		*-35.2%*	*-34.1%*
Average Annual Change from 1990 *(Percent)*		*-2.8%*	*-2.6%*
Change from 2005 (Million Metric Tons CO_2e)			2.9
(Percent)			*1.7%*

Figure 15. U.S. Methane Emissions from Waste Management by Source, 1990-2006



Source: EIA estimates.

Table 17. U.S. Methane Emissions from Waste Management, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Landfills	239.2	202.9	153.4	146.3	138.3	139.2	144.4	142.2	144.2	146.7
Domestic Wastewater Treatment	13.2	14.2	14.8	15.0	15.2	15.3	15.5	15.6	15.8	15.9
Industrial Waste Water Treatment	7.2	8.1	8.5	8.5	8.2	8.3	8.2	8.3	8.2	8.5
Total	**259.6**	**225.1**	**176.8**	**169.8**	**161.7**	**162.8**	**168.1**	**166.2**	**168.3**	**171.2**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2005.* Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), web site www.ipcc-nggip.iges.or.jp/public/public.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Methane Emissions

Industrial Processes

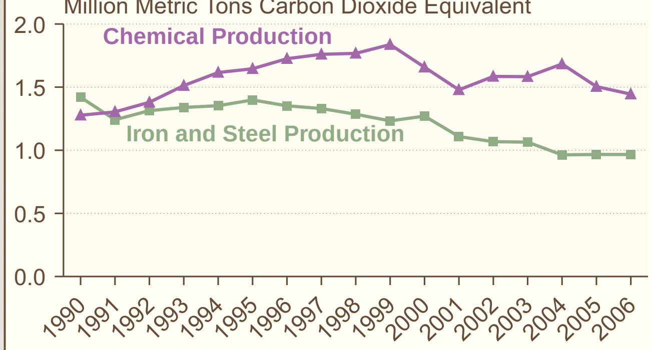
Summary

- Methane emissions are generated by industrial processes in the production of iron and steel and in chemical production (Figure 16 and Table 18).
- The slight growth in methane emissions from U.S. chemical production from 1990 to 2006 (0.2 $MMTCO_2e$) has been more than offset by declines in emissions from iron and steel production (0.5 $MMTCO_2e$) over the same period, leading to a net decline of 0.3 $MMTCO_2e$ in methane emissions from industrial processes.

Methane Emissions from Industrial Processes, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	2.7	2.5	2.4
Change from 1990 (Million Metric Tons CO_2e)		-0.2	-0.3
(Percent)		*-8.4%*	*-10.6%*
Average Annual Change from 1990 *(Percent)*		*-0.6%*	*-0.7%*
Change from 2005 (Million Metric Tons CO_2e)			-0.1
(Percent)			*-2.4%*

Figure 16. U.S. Methane Emissions from Industrial Processes by Source, 1990-2006



Source: EIA estimates.

Table 18. U.S. Methane Emissions from Industrial Processes, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Chemical Production										
Ethylene	0.4	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Ethylene Dichloride	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Styrene	0.3	0.5	0.5	0.5	0.4	0.4	0.4	0.5	0.4	0.4
Methanol	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.1	*
Carbon Black	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Subtotal	**1.3**	**1.6**	**1.8**	**1.7**	**1.5**	**1.6**	**1.6**	**1.7**	**1.5**	**1.4**
Iron and Steel Production										
Coke[a]	0.3	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Sinter	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pig Iron	1.0	1.1	1.0	1.0	0.9	0.8	0.8	0.8	0.8	0.8
Subtotal	**1.4**	**1.4**	**1.2**	**1.3**	**1.1**	**1.1**	**1.1**	**1.0**	**1.0**	**1.0**
Total	**2.7**	**3.0**	**3.1**	**2.9**	**2.6**	**2.7**	**2.6**	**2.6**	**2.5**	**2.4**

*Less than 0.05 $MMTCO_2e$.
P = preliminary data.
Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.
Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2005.* Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), web site www.ipcc-nggip.iges.or.jp/public/public.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Nitrous Oxide Emissions

Total Emissions

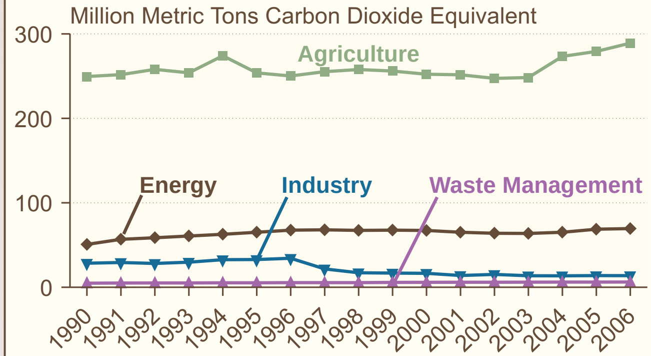
Summary

- Nitrous oxide emissions represent about 5 percent of all U.S. greenhouse gas emissions.
- The major sources of U.S. nitrous oxide emissions are agriculture and energy use, with industrial processes and waste management making smaller contributions (Table 19). The largest source is agricultural activities (Figure 17), including nitrogen fertilization of soils and disposal of animal wastes.
- Annual U.S. nitrous oxide emissions rose from 1990 to 1994, then fell from 1994 to 2003. They began rising sharply from 2003 to 2006, largely as a result of increases in the application of synthetic fertilizers.

U.S. Anthropogenic Nitrous Oxide Emissions, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	333.7	368.0	378.6
Change from 1990 (Million Metric Tons CO_2e)		34.2	44.9
(Percent)		*10.3%*	*13.4%*
Average Annual Change from 1990 *(Percent)*		*0.7%*	*0.8%*
Change from 2005 (Million Metric Tons CO_2e)			10.6
(Percent)			*2.9%*

Figure 17. Nitrous Oxide Emissions by Source, 1990-2006



Source: EIA estimates.

Table 19. Estimated U.S. Emissions of Nitrous Oxide, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Agriculture										
Nitrogen Fertilization of Soils	187.1	187.7	193.1	189.8	189.6	185.6	187.1	212.5	217.4	226.7
Solid Waste of Domesticated Animals	61.9	65.6	62.3	61.8	61.4	61.1	60.7	60.3	61.2	61.7
Crop Residue Burning	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.6	0.6	0.6
Subtotal	**249.5**	**253.7**	**256.0**	**252.2**	**251.5**	**247.3**	**248.3**	**273.4**	**279.2**	**289.1**
Energy Use										
Mobile Combustion	37.4	51.2	53.0	52.2	50.6	49.6	49.2	50.3	53.8	54.8
Stationary Combustion	13.3	13.9	14.6	15.1	14.6	14.3	14.5	14.9	14.9	14.7
Subtotal	**50.8**	**65.2**	**67.7**	**67.2**	**65.1**	**64.0**	**63.7**	**65.2**	**68.7**	**69.5**
Industrial Sources	**28.6**	**32.9**	**16.8**	**16.6**	**14.0**	**15.2**	**13.6**	**13.6**	**13.9**	**13.8**
Waste Management										
Human Sewage in Wastewater	4.6	5.1	5.5	5.6	5.6	5.7	5.7	5.8	5.8	5.9
Waste Combustion	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4
Subtotal	**4.9**	**5.4**	**5.8**	**5.8**	**6.0**	**6.0**	**6.1**	**6.1**	**6.2**	**6.3**
Total	**333.7**	**357.1**	**346.3**	**341.9**	**336.6**	**332.5**	**331.7**	**358.3**	**368.0**	**378.6**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this chapter. Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), web site www.ipcc-nggip.iges.or.jp/public/public.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Nitrous Oxide Emissions

Agriculture

Summary

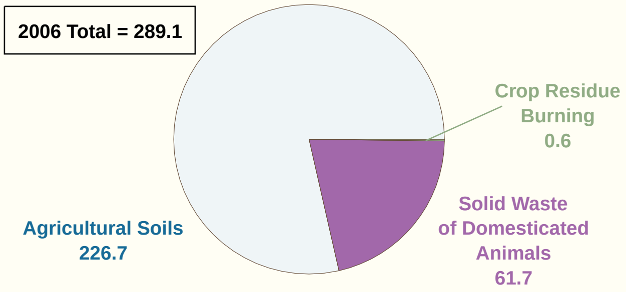
- Agricultural soils—both direct and indirect emissions—account for more than three-quarters of all U.S. emissions of nitrous oxide from agriculture (Figure 18 and Table 20).
- When nitrogen compounds are added to the soil, bacterial action is stimulated, leading to increased emissions of nitrous oxide unless the application precisely matches plant uptake and soil capture.
- Nitrous oxide is also released as part of the microbial denitrification of animal manure. Emissions are a function of animal size and manure production, the amount of nitrogen in the animal waste, and the method of managing the waste. Waste managed by solid storage or pasture range methods may emit 20 times as much nitrous oxide per unit of nitrogen content as waste managed in anaerobic lagoon and liquid systems.

U.S. Anthropogenic Nitrous Oxide Emissions from Agriculture, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	249.5	279.2	289.1
Change from 1990 (Million Metric Tons CO_2e)		29.7	39.6
(Percent)		*11.9%*	*15.9%*
Average Annual Change from 1990 *(Percent)*		*0.8%*	*0.9%*
Change from 2005 (Million Metric Tons CO_2e)			9.9
(Percent)			*3.5%*

Figure 18. Nitrous Oxide Emissions from Agriculture by Source, 2006

(Million Metric Tons Carbon Dioxide Equivalent)



Source: EIA estimates.

Table 20. U.S. Nitrous Oxide Emissions from Agricultural Sources, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Agricultural Soils										
Direct Emissions										
Biological Fixation in Crops	58.6	62.1	68.2	67.9	69.5	65.3	62.5	71.0	70.7	71.2
Nitrogen Fertilizers	53.1	51.2	47.7	45.6	44.4	45.6	48.0	54.3	57.9	63.0
Crop Residues	28.2	28.1	33.8	34.6	34.7	32.9	32.8	38.5	37.3	36.9
Other	4.5	4.7	4.7	4.6	4.7	4.7	4.8	4.8	4.8	4.8
Total Direct Emissions	***144.4***	***146.2***	***154.5***	***152.9***	***153.5***	***148.7***	***148.2***	***168.7***	***170.9***	***176.2***
Indirect Emissions										
Soil Leaching	36.3	35.2	32.8	31.3	30.6	31.4	33.0	37.1	39.5	43.0
Atmospheric Deposition	6.5	6.3	5.8	5.6	5.5	5.6	5.9	6.6	7.0	7.6
Total Indirect Emissions	***42.8***	***41.4***	***38.6***	***36.9***	***36.0***	***37.0***	***38.8***	***43.7***	***46.5***	***50.6***
Solid Waste of Domesticated Animals										
Cattle	57.5	61.1	57.9	57.4	56.9	56.7	56.3	55.8	56.4	56.8
Swine	1.5	1.6	1.6	1.6	1.6	1.6	1.7	1.7	1.7	1.7
Poultry	0.9	1.2	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4
Horses	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Sheep	1.0	0.8	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
Goats	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.5
Total Solid Waste	***61.9***	***65.6***	***62.3***	***61.8***	***61.4***	***61.1***	***60.7***	***60.3***	***61.2***	***61.7***
Crop Residue Burning	***0.5***	***0.5***	***0.5***	***0.6***	***0.6***	***0.5***	***0.5***	***0.6***	***0.6***	***0.6***
Total Agricultural Sources	**249.5**	**253.7**	**256.0**	**252.2**	**251.5**	**247.3**	**248.3**	**273.4**	**279.2**	**289.1**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

Nitrous Oxide Emissions

Energy Use

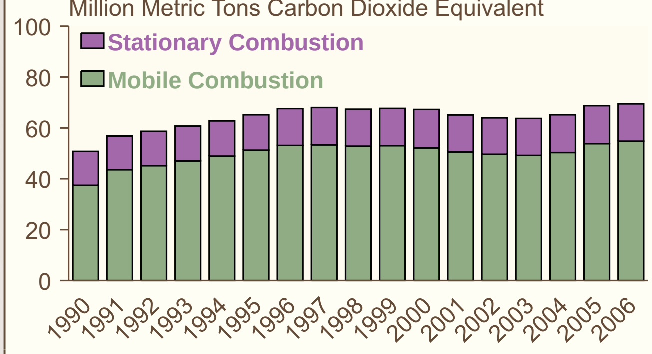
Summary

- Nitrous oxide is a byproduct of fuel combustion in mobile and stationary sources (Figure 19).
- More than three-quarters of U.S. nitrous oxide emissions from energy use can be traced to motor vehicles, primarily passenger cars and light trucks (Table 21). Emissions from passenger cars did not increase from 2005 to 2006, emissions from light trucks showed the largest increase, and the rest of the increase in vehicle emissions of nitrous oxide is attributed to off-road vehicles (included in "Other Mobile Sources").
- Nitrous oxide emissions from motor vehicles are caused by the conversion of nitrogen oxides into nitrous oxide by catalytic converters. Because the normal operating temperature of catalytic converters is high enough to cause the thermal decomposition of nitrous oxide, emissions in this category result primarily from "cold starts" and defective catalytic converters.
- Nitrous oxide emissions from stationary combustion sources are dominated by coal-fired generation at electric power plants.

U.S. Anthropogenic Nitrous Oxide Emissions from Energy Use, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	50.8	68.7	69.5
Change from 1990 (Million Metric Tons CO_2e)		18.0	18.7
(Percent)		*35.4%*	*36.8%*
Average Annual Change from 1990 *(Percent)*		*2.0%*	*2.0%*
Change from 2005 (Million Metric Tons CO_2e)			0.7
(Percent)			*1.1%*

Figure 19. Nitrous Oxide Emissions from Energy Use by Source, 1990-2006



Source: EIA estimates.

Table 21. U.S. Nitrous Oxide Emissions from Energy Use, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Item	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Mobile Combustion										
Motor Vehicles	***33.9***	***47.6***	***49.3***	***48.3***	***46.9***	***46.0***	***45.8***	***46.6***	***49.6***	***50.2***
Passenger Cars	21.6	28.5	28.4	27.6	26.7	25.6	24.9	24.6	25.6	25.6
Light-Duty Trucks	10.4	16.9	18.4	18.1	17.7	17.8	18.2	19.1	21.2	21.8
Other Motor Vehicles	1.8	2.2	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.8
Other Mobile Sources	***3.6***	***3.6***	***3.7***	***3.9***	***3.6***	***3.6***	***3.4***	***3.7***	***4.2***	***4.6***
Total	**37.4**	**51.2**	**53.0**	**52.2**	**50.6**	**49.6**	**49.2**	**50.3**	**53.8**	**54.8**
Stationary Combustion										
Residential and Commercial	1.4	1.4	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.2
Industrial	4.7	4.9	4.9	4.9	4.6	4.4	4.3	4.6	4.5	4.5
Electric Power	7.2	7.7	8.6	8.9	8.7	8.8	9.0	9.0	9.2	9.1
Total	**13.3**	**13.9**	**14.6**	**15.1**	**14.6**	**14.3**	**14.5**	**14.9**	**14.9**	**14.7**
Total from Energy Use	**50.8**	**65.2**	**67.7**	**67.2**	**65.1**	**64.0**	**63.7**	**65.2**	**68.7**	**69.5**

*Less than 50,000 metric tons carbon dioxide equivalent.
P = preliminary data.
Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.
Sources: Calculations based on vehicle miles traveled from U.S. Department of Transportation, *Federal Highway Statistics* (various years), Table VM-1, and current year preliminary estimates calculated using growth rates from EIA, *Short-Term Energy Outlook* (various years). Other Mobile Sources calculations based on Oak Ridge National Laboratory, *Transportation Energy Data Book*; EIA, *Fuel Oil and Kerosene Sales*, *State Energy Data Report*, and *Petroleum Supply Annual* (various years). Passenger car and light-duty truck emissions coefficients from U.S. Environmental Protection Agency, Office of Air and Radiation, *Emissions of Nitrous Oxide From Highway Mobile Sources: Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996*, EPA-420-R-98-009 (Washington DC, August 1998). Emissions coefficients from Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), web site www.ipcc-nggip.iges.or.jp/public/public.htm.

Nitrous Oxide Emissions

Industrial Sources

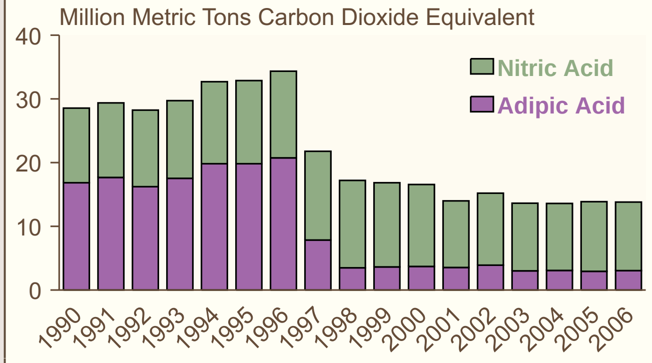
Summary

- Production of adipic acid and nitric acid releases nitrous oxide as a byproduct (Table 22).
- Adipic acid is a fine white powder used primarily in the manufacture of nylon fibers and plastics. Three companies operate four U.S. plants that manufacture adipic acid by oxidizing a ketone-alcohol mixture with nitric acid. This chemical reaction causes nitrous oxide emissions.
- A large decline in nitrous oxide emissions from industrial processes since 1996 (Figure 20) is the result of emissions control technology installed at three of the four adipic acid plants in the United States.
- Nitric acid, a primary ingredient in fertilizers, usually is manufactured by oxidizing ammonia with a platinum catalyst. This oxidation causes nitrous oxide emissions.

U.S. Anthropogenic Nitrous Oxide Emissions from Industrial Sources, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	28.6	13.9	13.8
Change from 1990 (Million Metric Tons CO_2e)		-14.7	-14.8
(Percent)		*-51.5%*	*-51.7%*
Average Annual Change from 1990 *(Percent)*		*-4.7%*	*-4.4%*
Change from 2005 (Million Metric Tons CO_2e).			-0.1
(Percent)			*-0.4%*

Figure 20. Nitrous Oxide Emissions from Industry by Source, 1990-2006



Source: EIA estimates.

Table 22. U.S. Nitrous Oxide Emissions from Industrial Sources, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Adipic Acid										
Controlled Sources	1.0	1.1	1.5	1.6	1.4	1.6	1.6	1.6	1.6	1.6
Uncontrolled Sources	15.9	18.7	2.1	2.1	2.1	2.3	1.4	1.4	1.4	1.4
Subtotal	**16.8**	**19.8**	**3.6**	**3.7**	**3.5**	**3.9**	**3.0**	**3.1**	**2.9**	**3.0**
Nitric Acid.	**11.7**	**13.1**	**13.2**	**12.9**	**10.4**	**11.3**	**10.6**	**10.5**	**10.9**	**10.8**
Total Known Industrial Sources. . . .	**28.6**	**32.9**	**16.8**	**16.6**	**14.0**	**15.2**	**13.6**	**13.6**	**13.9**	**13.8**

P = preliminary data.
Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Nitrous Oxide Emissions

Waste Management

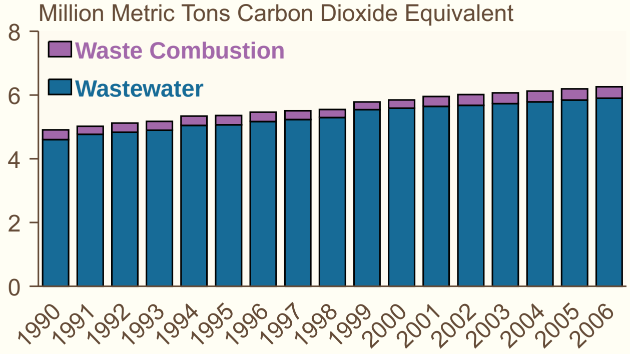
Summary

- Emissions from human sewage account for nearly all U.S. nitrous oxide emissions from waste management. The remainder is associated with waste combustion (Figure 21 and Table 23).
- Estimates of nitrous oxide emissions from human waste are scaled to population size and per-capita intake of protein.
- Nitrous oxide is emitted from wastewater that contains nitrogen-based organic materials, such as those found in human or animal waste. Factors that influence the amount of nitrous oxide generated from wastewater include temperature, acidity, biochemical oxygen demand, and nitrogen concentration.

U.S. Anthropogenic Nitrous Oxide Emissions from Waste Management, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	4.9	6.2	6.3
Change from 1990 (Million Metric Tons CO_2e)		1.3	1.4
(Percent)		*26.2%*	*27.6%*
Average Annual Change from 1990 *(Percent)*		*1.6%*	*1.5%*
Change from 2005 (Million Metric Tons CO_2e)			0.1
(Percent)			*1.1%*

Figure 21. Nitrous Oxide Emissions from Waste Management by Source, 1990-2006



Source: EIA estimates.

Table 23. U.S. Nitrous Oxide Emissions from Waste Management, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Domestic and Commercial Wastewater	4.6	5.1	5.5	5.6	5.6	5.7	5.7	5.8	5.8	5.9
Waste Combustion	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4
Total	**4.9**	**5.4**	**5.8**	**5.8**	**6.0**	**6.0**	**6.1**	**6.1**	**6.2**	**6.3**

P = preliminary data.
Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

High-GWP Gases

Total Emissions

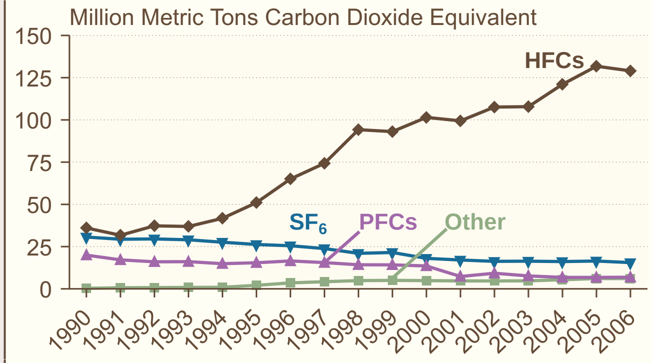
Summary

- Greenhouse gases with high global warming potential (high-GWP gases) are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), which together represented just over 2 percent of U.S. greenhouse gas emissions in 2006.
- Emissions estimates for the high-GWP gases are provided to EIA by the EPA's Office of Air and Radiation. The estimates are derived from the EPA Vintaging Model.
- Emissions of high-GWP gases have increased steadily since 1990 (Figure 22 and Table 24), largely because HFCs are being used to replace chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and other ozone-depleting substances that are being phased out under the terms of the Montreal Protocol, which entered into force on January 1, 1989.
- PFC emissions have declined since 1990 as a result of production declines in the U.S. aluminum industry as well as industry efforts to lower emissions per unit of output.

U.S. Anthropogenic Emissions of High-GWP Gases, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	87.1	161.2	157.6
Change from 1990 (Million Metric Tons CO_2e)		74.1	70.5
(Percent)		*85.1%*	*81.0%*
Average Annual Change from 1990 *(Percent)*		*4.2%*	*3.8%*
Change from 2005 (Million Metric Tons CO_2e)			-3.6
(Percent)			*-2.2%*

Figure 22. U.S. Anthropogenic Emissions of High-GWP Gases, 1990-2006



Source: U.S. EPA estimates.

Table 24. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Hydrofluorocarbons	36.1	51.0	93.1	101.5	99.4	107.6	107.8	121.1	131.8	129.0
Perfluorocarbons	20.0	15.5	14.2	13.6	7.4	9.3	7.7	6.8	6.8	6.9
Other HFCs, PFCs/PFPEs	0.4	2.1	5.0	4.9	4.7	4.7	4.7	5.4	6.1	6.1
Sulfur Hexafluoride	30.7	26.3	21.6	18.1	17.1	16.3	16.4	16.2	16.5	15.6
Total Emissions	**87.1**	**94.9**	**133.9**	**138.0**	**128.6**	**137.8**	**136.6**	**149.4**	**161.2**	**157.6**

P = preliminary data.

Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September and October 2007).

High-GWP Gases

Hydrofluorocarbons

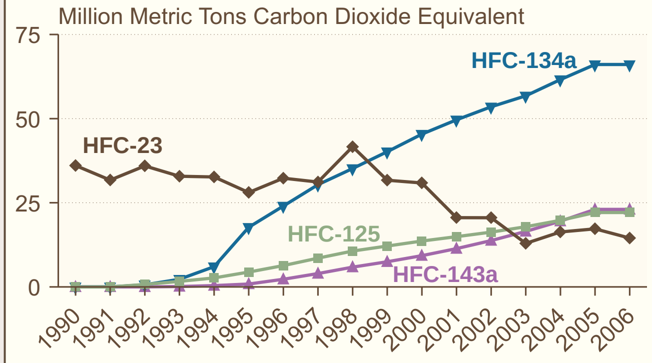
Summary

- HFCs are compounds that contain carbon, hydrogen, and fluorine. Although they do not destroy stratospheric ozone, they are powerful greenhouse gases.
- HFCs are used in many applications, such as solvents, residential and commercial refrigerants, firefighting agents, and propellants for aerosols.
- Emissions of substitutes for ozone-depleting substances, including HFC-32, HFC-125, HFC-134a, and HFC-236fa, have grown from trace amounts in 1990 to more than 110 $MMTCO_2e$ in 2006 (Figure 23).
- Nearly 90 percent of the growth in HFC emissions since 1990 can be attributed to the use of HFCs as replacements for ozone-depleting substances. The market is expanding, with HFCs used in fire protection applications to replace Halon 1301 and Halon 1211.
- Since 1999, HFC-134a—used as a replacement for CFCs in air conditioners for passenger cars, trucks, trains, and buses—has accounted for the largest share of HFC emissions (Table 25).

U.S. Anthropogenic Emissions of HFCs, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	36.1	131.8	129.0
Change from 1990 (Million Metric Tons CO_2e)		95.7	93.0
(Percent)		*265.4%*	*257.8%*
Average Annual Change from 1990 *(Percent)*		*9.0%*	*8.3%*
Change from 2005 (Million Metric Tons CO_2e)			-2.7
(Percent)			*-2.1%*

Figure 23. U.S. Anthropogenic Emissions of HFCs, 1990-2006



Source: U.S. EPA estimates.

Table 25. U.S. Emissions of Hydrofluorocarbons, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
HFC-23	36.1	28.1	31.7	30.9	20.6	20.6	12.9	16.3	17.3	14.5
HFC-32	0.0	0.0	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4
HFC-125	0.0	4.4	12.1	13.6	14.9	16.3	17.9	19.8	22.1	22.1
HFC-134a	0.0	17.7	40.2	45.4	49.7	53.5	56.8	61.6	66.1	66.1
HFC-143a	0.0	0.9	7.5	9.3	11.4	13.8	16.5	19.5	23.0	23.0
HFC-236fa	0.0	0.0	1.3	2.0	2.6	3.2	3.5	3.5	2.9	2.9
Total HFCs	**36.1**	**51.0**	**93.1**	**101.5**	**99.4**	**107.6**	**107.8**	**121.1**	**131.8**	**129.0**

P = preliminary data.
Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September and October 2007).

High-GWP Gases

Perfluorocarbons

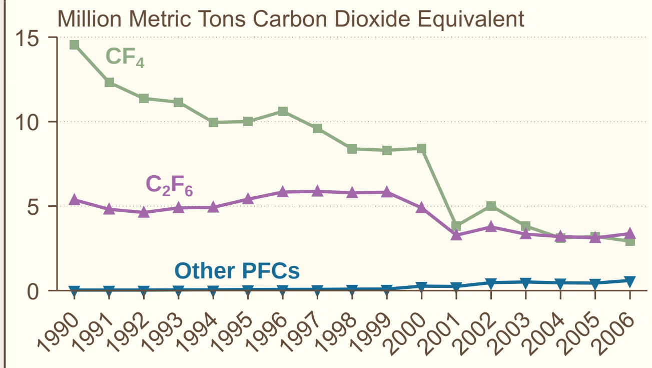
Summary

- The two principal sources of PFC emissions are domestic aluminum production and semiconductor manufacture, which yield perfluoromethane (CF_4) and perfluoroethane (C_2F_6) (Figure 24 and Table 26).
- While PFC emissions from aluminum production have declined markedly since 1990, the decline has been offset in part by increased emissions from semiconductor manufacturing.
- Emissions from process inefficiencies during aluminum production (known as "anode effects") have been greatly reduced; in addition, high costs for alumina and energy have led to production cutbacks.
- Perfluoroethane is used as an etchant and cleaning agent in semiconductor manufacturing. The portion of the gas that does not react with the materials is emitted to the atmosphere.

U.S. Anthropogenic Emissions of PFCs, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e). . . .	20.0	6.8	6.9
Change from 1990 (Million Metric Tons CO_2e)		-13.2	-13.1
(Percent)		*-66.0%*	*-65.5%*
Average Annual Change from 1990 *(Percent)*		*-6.9%*	*-6.4%*
Change from 2005 (Million Metric Tons CO_2e).			0.1
(Percent)			*1.8%*

Figure 24. U.S. Anthropogenic Emissions of PFCs, 1990-2006



Source: U.S. EPA estimates.

Table 26. U.S. Emissions of Perfluorocarbons, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
CF_4	14.6	10.0	8.3	8.4	3.8	5.0	3.8	3.1	3.2	2.9
C_2F_6	5.4	5.4	5.8	4.9	3.3	3.8	3.3	3.2	3.1	3.4
NF_3	*	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.4
C_3F_8	*	*	*	0.1	0.1	0.1	0.1	*	*	*
C_4F_8	*	*	*	*	*	0.1	0.1	0.1	0.1	*
Total HFCs.	**20.0**	**15.5**	**14.2**	**13.6**	**7.4**	**9.3**	**7.7**	**6.8**	**6.8**	**6.9**

*Less than 0.05 million metric tons carbon dioxide equivalent.
P = preliminary data.
Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September and October 2007).

High-GWP Gases

Sulfur Hexafluoride

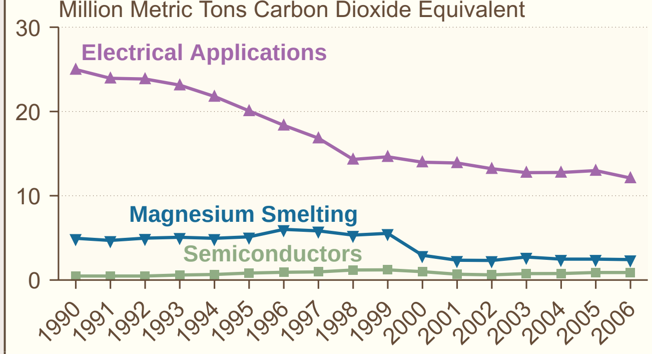
Summary

- SF_6, an excellent dielectric gas for high-voltage applications, is used primarily in electrical applications—as an insulator and arc interrupter for circuit breakers, switch gear, and other equipment in electricity transmission and distribution systems.
- SF_6 is also used in magnesium metal casting, as a cover gas during magnesium production, and as an atmospheric tracer for experimental purposes.
- Other, minor applications of SF_6 include leak detection and the manufacture of loudspeakers and lasers.
- Industry efforts to reduce emissions of SF_6 from electrical power systems have led to a decline in emissions since 1990 (Figure 25 and Table 27).

U.S. Anthropogenic Emissions of SF_6, 1990, 2005, and 2006

	1990	2005	2006
Estimated Emissions (Million Metric Tons CO_2e)	30.7	16.5	15.6
Change from 1990 (Million Metric Tons CO_2e)		-14.2	-15.1
(Percent)		*-46.2%*	*-49.3%*
Average Annual Change from 1990 *(Percent)*		*-4.1%*	*-4.2%*
Change from 2005 (Million Metric Tons CO_2e)			-0.9
(Percent)			*-5.7%*

Figure 25. U.S. Anthropogenic Emissions of SF_6 by Source, 1990-2006



Source: U.S. EPA estimates.

Table 27. U.S. Emissions of Sulfur Hexafluoride by Source, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Electrical Applications	25.2	20.3	14.8	14.1	14.0	13.3	12.9	12.9	13.1	12.2
Magnesium Smelting	5.0	5.2	5.6	3.0	2.4	2.3	2.8	2.5	2.5	2.4
Semiconductors	0.5	0.8	1.2	1.0	0.7	0.6	0.8	0.8	0.9	0.9
Total SF_6	**30.7**	**26.3**	**21.6**	**18.1**	**17.1**	**16.3**	**16.4**	**16.2**	**16.5**	**15.6**

P = preliminary data.
Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September and October 2007).

Land Use

Overview

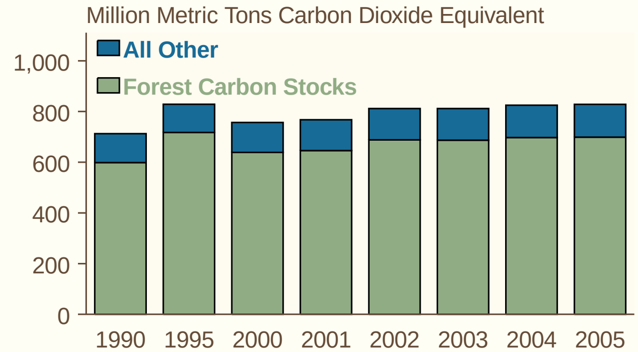
Summary

- Land use, land-use change, and forestry activities in 2005 resulted in net sequestration of 828.5 million metric tons CO_2 equivalent (Table 28), equal to 11.5 percent of U.S. greenhouse gas emissions in 2005, which totaled 7,181.4 $MMTCO_2e$.
- Net carbon sequestration from land use, land-use change, and forestry activities in 2005 was 16 percent greater than in 1990 (Figure 26). The increase resulted primarily from a higher rate of net carbon accumulation in forest carbon stocks.
- Net carbon accumulation in Cropland Remaining Cropland, Land Converted to Grassland, and Settlements Remaining Settlements increased from 1990 to 2005.
- Net carbon accumulation in landfilled yard trimmings and food scraps decreased from 1990 to 2005. Grassland Remaining Grassland had net carbon emissions in 1990 and 1991, became a net carbon sink from 1992 to 1994, and since then has remained a fairly constant emissions source.
- Emissions from Land Converted to Cropland declined from 1990 to 2005.

Total U.S. Carbon Sequestration from Land-Use Change and Forests, 1990, 2004, and 2005

	1990	2004	2005
Estimated Sequestration (Million Metric Tons)	712.8	824.8	828.5
Change from 1990 (Million Metric Tons)		112.0	115.7
(Percent)		*15.7%*	*16.2%*
Average Annual Change from 1990 *(Percent)*		*1.1%*	*1.0%*
Change from 2004 (Million Metric Tons)			0.45
(Percent)			*-1.3%*

Figure 26. Carbon Sequestration from Land Use and Land-Use Change, 1990, 1995, and 2000-2005



Source: U.S. EPA estimates.

Table 28. Net Carbon Dioxide Sequestration from U.S. Land-Use Change and Forestry, 1990, 1995, and 2000-2005
(Million Metric Tons Carbon Dioxide Equivalent)

Component	1990	1995	2000	2001	2002	2003	2004	2005
Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks	598.5	717.5	638.7	645.7	688.1	687.0	697.3	698.7
Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stocks and Liming Emissions[a]	28.1	37.4	36.5	38.0	37.8	38.3	39.4	39.4
Land Converted to Cropland: Changes in Agricultural Soil Carbon Stocks	-8.7	-7.2	-7.2	-7.2	-7.2	-7.2	-7.2	-7.2
Grassland Remaining Grassland: Changes in Agricultural Soil Carbon Stocks	-0.1	-16.4	-16.3	-16.2	-16.2	-16.2	-16.1	-16.1
Land Converted to Grassland: Changes in Agricultural Soil Carbon Stocks	14.6	16.3	16.3	16.3	16.3	16.3	16.3	16.3
Settlements Remaining Settlements: Urban Trees[b]	57.5	67.8	78.2	80.2	82.3	84.4	86.4	88.5
Other: Landfilled Yard Trimmings and Food Scraps	22.8	13.3	10.5	10.6	10.8	9.3	8.7	8.8
Total Net Flux	**712.8**	**828.8**	**756.7**	**767.5**	**811.9**	**811.9**	**824.8**	**828.5**

[a]Estimates include carbon stock changes in mineral soils and organic soils on Cropland Remaining Cropland and liming emissions from all Cropland, Grassland, and Settlement categories.
[b]Estimates include C stock changes on both Settlements Remaining Settlements, and Land Converted to Settlements.
Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Land Use

Forest Lands and Harvested Wood Pools

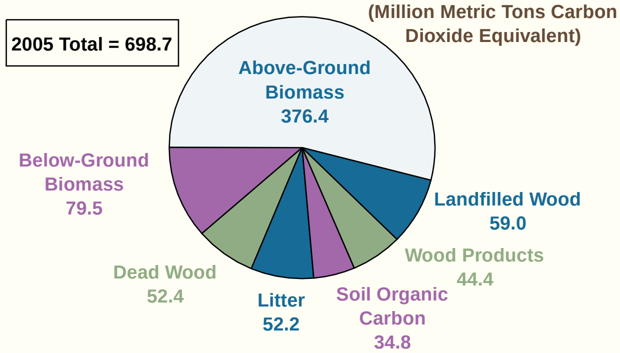
Summary

- Carbon sequestration attributed to forest land remaining forest land in 2005 totaled 698.7 million metric tons carbon dioxide equivalent (Figure 27 and Table 29).
- The calculation methods for this year's annualized estimates of forest ecosystem carbon stocks differ from those used in previous inventories, as a result of efforts to improve the consistency of national, State, and sub-State data sets. The new estimate of carbon stocks sequestered in forest land in 1990 is 23 percent lower, and the estimate for 2004 is 9 percent higher, than the values in last year's inventory.
- The chaparral ecosystem fails to meet the definition of forest, and more current forest data omit this vegetation type; however, it has been discovered that older forest survey data included it. To ensure consistency, chaparral has been removed from the older estimates in this year's inventory, resulting in lower estimates of carbon stocks for California, especially in the earlier years.
- The sequestration estimates for harvested wood products have also been revised, based on more detailed product and trade data and updated parameters for discard and decay. As a result, the estimates for average annual sequestration for harvested wood products from 1990 through 2004 are about 47 percent less than in last year's inventory. Virtually all of the decrease is in the estimates of annual additions to landfills and dumps.

Carbon Sequestration from Forest Lands and Harvested Wood Pools, 1990, 2004, and 2005

	1990	2004	2005
Estimated Sequestration (Million Metric Tons)	598.5	697.3	698.7
Change from 1990 (Million Metric Tons)		98.8	100.2
(Percent)		*16.5%*	*16.7%*
Average Annual Change from 1990 *(Percent)*		*1.0%*	*1.0%*
Change from 2004 (Million Metric Tons)			1.4
(Percent)			*0.2%*

Figure 27. Carbon Sequestration from Forest Lands and Harvested Wood Pools, 2005



Source: U.S. EPA estimates.

Table 29. Net Carbon Dioxide Sequestration in U.S. Forests and Harvested Wood Pools, 1990, 1995, and 2000-2005
(Million Metric Tons Carbon Dioxide Equivalent)

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005
Forests	**466.5**	**602.0**	**529.4**	**555.5**	**595.3**	**595.3**	**595.3**	**595.3**
Above-Ground Biomass	251.8	331.0	347.1	360.4	376.4	376.4	376.4	376.4
Below-Ground Biomass	63.9	69.8	73.9	76.4	79.5	79.5	79.5	79.5
Dead Wood	36.7	60.9	48.2	50.0	52.4	52.4	52.4	52.4
Litter	65.6	49.5	35.8	47.1	52.2	52.2	52.2	52.2
Soil Organic Carbon	48.5	90.8	24.5	21.6	34.8	34.8	34.8	34.8
Harvested Wood	**132.0**	**115.5**	**109.3**	**90.2**	**92.8**	**91.7**	**101.9**	**103.4**
Wood Products	63.1	53.5	46.2	31.2	34.1	33.4	43.3	44.4
Landfilled Wood	68.9	62.0	63.1	59.0	58.7	58.3	58.7	59.0
Total	**598.5**	**717.5**	**638.7**	**645.7**	**688.1**	**687.0**	**697.3**	**698.7**

Notes: The sums of the annual net stock changes in this table (shown in the "Total" row) represent estimates of the actual net flux between the total forest carbon pool and the atmosphere. Forest estimates are based on periodic measurements; harvested wood estimates are based on annual surveys and models. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Land Use

Croplands and Grasslands

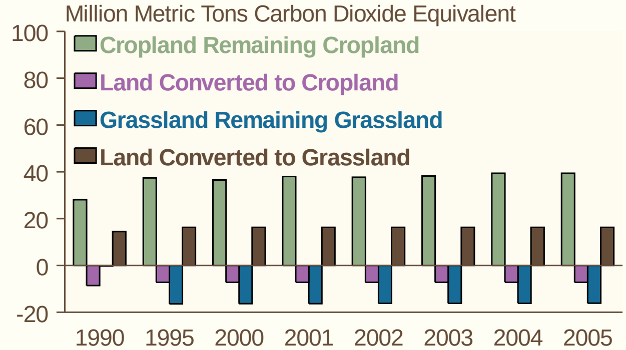
Summary

- Annual carbon dioxide emissions from organic cropland soils are subdivided between Cropland Remaining Cropland and Land Converted to Cropland (Table 30); in last year's inventory they were reported only for Cropland Remaining Cropland. The reapportionment resulted in an average annual increase in emissions of 71.4 percent for soil carbon stock changes in Land Converted to Cropland from 1990 to 2004 and a shift of this category to an overall source (Figure 28) from an overall sink in the previous report.
- The adjustments for Cropland and Grassland categories, applied to Grassland Remaining Grassland, resulted in an average annual increase in emissions of 46.2 percent for soil carbon stock changes from 1990 to 2004. Applied to Land Converted to Grassland, the adjustments resulted in an average annual decrease in sinks of 21.1 percent from 1990 to 2004.

Total U.S. Carbon Sequestration from Croplands and Grasslands, 1990, 2004, and 2005

	1990	2004	2005
Estimated Sequestration (Million Metric Tons)	33.8	32.3	32.4
Change from 1990 (Million Metric Tons)		-1.5	-1.4
(Percent)		*-4.4%*	*-4.1%*
Average Annual Change from 1990 *(Percent)*		*-0.3%*	*-0.3%*
Change from 2004 (Million Metric Tons)			0.1
(Percent)			*0.3%*

Figure 28. Carbon Sequestration from Croplands and Grasslands, 1990, 1995, and 2000-2005



Source: U.S. EPA estimates.

Table 30. Net Carbon Dioxide Sequestration from Croplands and Grasslands, 1990, 1995, and 2000-2005
(Million Metric Tons Carbon Dioxide Equivalent)*

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005
Cropland Remaining Cropland	**28.1**	**37.4**	**36.5**	**38.0**	**37.8**	**38.3**	**39.4**	**39.4**
Mineral Soils	60.2	69.5	68.5	70.1	70.4	70.5	71.0	71.1
Organic Soils	-27.4	-27.7	-27.7	-27.7	-27.7	-27.7	-27.7	-27.7
Liming of Soils	-4.7	-4.4	-4.3	-4.4	-5.0	-4.6	-3.9	-4.0
Land Converted to Cropland	**-8.7**	**-7.2**	**-7.2**	**-7.2**	**-7.2**	**-7.2**	**-7.2**	**-7.2**
Mineral Soils	-6.2	-4.6	-4.6	-4.6	-4.6	-4.6	-4.6	-4.6
Organic Soils	-2.4	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6
Liming of Soils	—	—	—	—	—	—	—	—
Grassland Remaining Grassland	**0.1**	**-16.4**	**-16.3**	**-16.2**	**-16.2**	**-16.2**	**-16.1**	**-16.1**
Mineral Soils	3.7	-12.7	-12.6	-12.6	-12.5	-12.5	-12.5	-12.4
Organic Soils	-3.9	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7
Liming of Soils	—	—	—	—	—	—	—	—
Land Converted to Grassland	**14.6**	**16.3**	**16.3**	**16.3**	**16.3**	**16.3**	**16.3**	**16.3**
Mineral Soils	15.0	17.2	17.2	17.2	17.2	17.2	17.2	17.2
Organic Soils	-0.5	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9
Liming of Soils	—	—	—	—	—	—	—	—

*All values for the years 1990 and 1995 and all "Liming of Soils" values for 2000 through 2004 are based on historical data. The other values in the table are based on extrapolation of historical data.

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Land Use

Urban Trees, Yard Trimmings, and Food Scraps

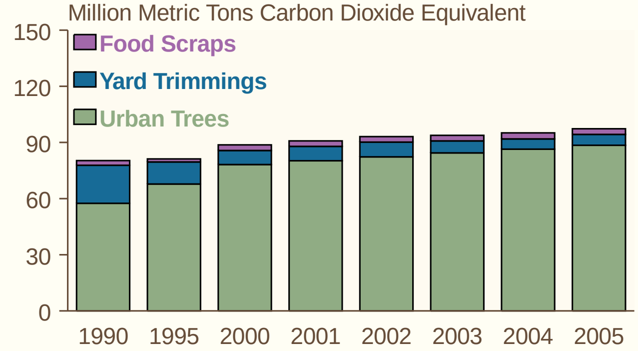
Summary

- Urban trees accounted for nearly all (91 percent) of the carbon sequestration attributed to urban trees, yard trimmings, and food scraps in 2005 (Figure 29 and Table 31).
- For yard trimmings and food scrap carbon stocks in landfills, the value for the initial carbon content of leaves was updated for the current inventory based on updated experimental results. This recalculation had the effect of reducing both the stocks of carbon from leaves and the annual flux for yard trimmings and food scraps.
- In last year's inventory, changes in yard trimming and food scrap carbon stocks in landfills were included under Settlements Remaining Settlements. Although carbon stock changes in yard trimmings and food scraps are associated with settlements, removals do not occur within settlements. Therefore, yard trimming and food scrap carbon storage is now reported under "Other."

Total U.S. Carbon Sequestration from Urban Trees, Yard Trimmings, and Food Scraps, 1990, 2004, and 2005

	1990	2004	2005
Estimated Sequestration (Million Metric Tons)	80.3	95.1	97.3
Change from 1990 (Million Metric Tons)		14.8	16.9
(Percent)		*18.4%*	*21.0%*
Average Annual Change from 1990 *(Percent)*		*1.1%*	*1.3%*
Change from 2004 (Million Metric Tons)			2.2
(Percent)			*2.3%*

Figure 29. Carbon Sequestration from Urban Trees, Yard Trimmings, and Food Scraps, 1990, 1995, and 2000-2005



Source: U.S. EPA estimates.

Table 31. Net Carbon Dioxide Sequestration in U.S. Urban Trees, Yard Trimmings, and Food Scraps, 1990, 1995, and 2000-2005
(Million Metric Tons Carbon Dioxide Equivalent)

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005
Urban Trees	**57.5**	**67.8**	**78.2**	**80.2**	**82.3**	**84.4**	**86.4**	**88.5**
Yard Trimmings	**20.3**	**11.8**	**7.5**	**7.7**	**7.9**	**6.4**	**5.5**	**5.8**
Grass	2.4	1.2	0.8	0.9	0.9	0.7	0.6	0.7
Leaves	8.2	4.7	2.9	3.0	3.1	2.5	2.1	2.2
Branches	9.7	5.8	3.7	3.8	3.9	3.2	2.8	2.9
Food Scraps	**2.5**	**1.6**	**3.0**	**2.9**	**2.9**	**3.0**	**3.2**	**3.0**
Total Net Flux	**80.3**	**81.2**	**88.7**	**90.8**	**93.1**	**93.8**	**95.1**	**97.3**

Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, EPA 430-R-07-002 (Washington, DC, April 2007), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Land Use

Tree Planting and Surface Albedo

Surface albedo is a measure of the extent to which the Earth's surface reflects or absorbs sunlight. Lighter surfaces, such as bare ground covered with snow, have a relatively *high albedo* and *reflect* almost all the energy (heat) of incoming solar radiation. Darker surfaces, such as deep oceans and dense forests, have a relatively *low albedo* and *absorb* almost all the heat of incoming solar radiation. Consequently, when changing conditions cause a decrease in surface albedo—for example, when trees are planted on lands that receive substantial winter snowfall—they can increase the capacity of the affected area to absorb heat from the sun, with an overall warming effect.

Afforestation and reforestation to increase carbon sequestration are permitted activities under the Clean Development Mechanism of the Kyoto Protocol and other climate change mitigation programs. Project developers can earn carbon credits or offsets for the amounts of carbon sequestered by the trees they plant. Recent research, however, has shown the importance of changes in surface albedo caused by tree planting, which should be considered in tandem with the increases in carbon sequestration achieved by such projects.[20, 21, 22, 23, 24] Tree planting increases carbon sequestration; but, depending on local and regional conditions, it can also decrease surface albedo.[25]

The recent scientific studies cited above have shown that, in the Earth's middle and high latitudes, the warming effect of lower surface albedo that results from afforestation or reforestation can have an unintended net warming effect. Before the advent of industrialization, humans were already affecting the climate by clearing forests to plant crops, an activity that increased surface albedo.[26] Thus, the net result of preindustrial changes in land use was negative climate forcing (cooling). According to one recent study,[27] the rate of cooling induced by preindustrial deforestation was similar in magnitude to the current rate of positive climate forcing (warming) caused by anthropogenic emissions of ozone (O_3), nitrous oxide (N_2O), and halocarbons.

Researchers have also compared the magnitude of the positive climate forcing caused by modern-day tree planting (as a result of lowered albedo) with the negative forcing that results from increased carbon sequestration by newly planted trees. Their results indicate that, in the middle and high latitudes, the warming effects of afforestation and reforestation activities could partially or completely offset the cooling effects—especially in snow-covered areas, where the difference in albedo between snow-covered bare ground and partially snow-covered forested areas is greatest. This finding has policy implications in general for climate change mitigation efforts and specifically for the valuation of carbon credits earned through reforestation and afforestation activities.

The albedo effect is less significant in tropical zones, where research models indicate that deforestation causes warming.[28] In tropical forest areas, loss of tree cover reduces leafy surface area and, as a result, slows the release of water vapor into the atmosphere. Slower evaporation rates, in turn, have a negative effect on cloud formation above tropical rain forests. Because the clouds reflect incoming solar radiation, they lower surface temperatures. With less cloud cover, more incoming solar radiation reaches the Earth's surface, and temperatures rise.

(continued on page 42)

[20]R.A. Betts, P. D. Falloon, K.K. Goldewijk, and N. Ramankutty, "Biogeophysical Effects of Land Use on Climate: Model Simulations of Radiative Forcing and Large-Scale Temperature Change," *Agricultural and Forest Meteorology*, Vol. 142 (2007), pp. 216-233.

[21]R.A. Betts, K.K. Goldewijk, and N. Ramankutty, "Radiative Forcing by Anthropogenic Surface Albedo Change Before and Since 1750," *Hadley Center Technical Note*, No. 70 (2006), web site www.metoffice.gov.uk/research/hadleycentre/pubs/HCTN/HCTN_70.pdf.

[22]J.J. Feddema, K.W. Oleson, G.B. Bonan, L.O. Mearns, L.E. Buja, G.A. Meehl, and W.M. Washington, "The Importance of Land-Cover Change in Simulating Future Climates," *Science*, Vol. 310, No. 5754 (December 9, 2005), pp. 1674-1678.

[23]A. Fischlin, G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, and A.A. Velichko, "Ecosystems, Their Properties, Goods, and Services," in *Climate Change 2007: Impacts, Adaptation and Vulnerability* (M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, eds. (Cambridge, UK: Cambridge University Press, 2007), pp. 211-272, web site www.ipcc.ch/ipccreports/ar4-wg2.htm.

[24]S.G. Gibbard, K. Caldeira, G. Bala, T.J. Philips, and M. Wickett, "Climate Effects of Global Land Cover Change," *Geophysical Research Letters*, Vol. 32 (2005), p. L23705, web site www.llnl.gov/tid/lof/documents/pdf/324200.pdf.

[25]It is important to note that the planting of trees often has other ecological and societal benefits, which are not discussed here.

[26]S.G. Gibbard et al., "Climate Effects of Global Land Cover Change" (2005).

[27]R.A. Betts et al., "Biogeophysical Effects of Land Use on Climate: Model Simulations of Radiative Forcing and Large-Scale Temperature Change" (2007).

[28]J.J. Feddema et al., "The Importance of Land-Cover Change in Simulating Future Climates" (2005).

Land Use

Tree Planting and Surface Albedo

At the National Center for Atmospheric Research, researchers using the Parallel Climate Model (sponsored by the U.S. Department of Energy) have modeled climate change for three future periods—2000-2033, 2033-2066, and 2066-2100—considering in one case only the effects of atmospheric forcing and in another case the combined effects of atmospheric forcing and changes in land cover.[29] They found that forest-to-agriculture conversion in the Amazon rain forest causes significant warming, although the effects are not uniform across all tropical forests. (For example, in Indonesia, temperature changes from forest loss are minor in future scenarios, because the Asian monsoon compensates for the decrease in cloud formation relative to that over undisturbed forests.)

In the middle and, especially, high latitudes, there is increasing evidence that the radiative cooling effect derived from carbon sequestration by newly planted trees could be partially or completely offset by the radiative warming effect of reduced albedo. For example, the IPCC in its latest assessment notes that replacement of tundra vegetation by coniferous evergreen trees is likely to reduce regional albedo significantly and lead to a warming effect greater than the cooling effect of increased carbon sequestration.[30] In contrast, tree planting in tropical latitudes, where vegetation and cloud formation are linked, can double the radiative cooling benefit by reducing incoming solar radiation while also increasing carbon sequestration.

[29] J.J. Feddema et al., "The Importance of Land-Cover Change in Simulating Future Climates" (2005).

[30] Intergovernmental Panel on Climate Change, *Climate Change 2007—The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the IPCC (Cambridge, UK: Cambridge University Press, 2007).

Glossary

Acid stabilization: A circumstance where the pH of the waste mixture in an animal manure management system is maintained near 7.0, optimal conditions for methane production.

Aerobic bacteria: Microorganisms living, active, or occurring only in the presence of oxygen.

Aerobic decomposition: The breakdown of a molecule into simpler molecules or atoms by microorganisms under favorable conditions of oxygenation.

Aerosols: Airborne particles.

Afforestation: Planting of new forests on lands that have not been recently forested.

Agglomeration: The clustering of disparate elements.

Airshed: An area or region defined by settlement patterns or geology that results in discrete atmospheric conditions.

Albedo: The fraction of incident light or electromagnetic radiation that is reflected by a surface or body. See *Planetary albedo*.

Anaerobes: Organisms that live and are active only in the absence of oxygen.

Anaerobic bacteria: Microorganisms living, active, or occurring only in the absence of oxygen.

Anaerobic decomposition: The breakdown of molecules into simpler molecules or atoms by microorganisms that can survive in the partial or complete absence of oxygen.

Anaerobic lagoon: A liquid-based manure management system, characterized by waste residing in water to a depth of at least six feet for a period ranging between 30 and 200 days.

Anode: A positive electrode, as in a battery, radio tube, etc.

Anthracite: The highest rank of coal; used primarily for residential and commercial space heating. It is a hard, brittle, and black lustrous coal, often referred to as hard coal, containing a high percentage of fixed carbon and a low percentage of volatile matter. The moisture content of fresh-mined anthracite generally is less than 15 percent. The heat content of anthracite ranges from 22 to 28 million Btu per ton on a moist, mineral-matter-free basis. The heat content of anthracite coal consumed in the United States averages 25 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter). Note: Since the 1980's, anthracite refuse or mine waste has been used for steam electric power generation. This fuel typically has a heat content of 15 million Btu per ton or less.

Anthropogenic: Made or generated by a human or caused by human activity. The term is used in the context of global climate change to refer to gaseous emissions that are the result of human activities, as well as other potentially climate-altering activities, such as deforestation.

API Gravity: American Petroleum Institute measure of specific gravity of crude oil or condensate in degrees. An arbitrary scale expressing the gravity or density of liquid petroleum products. The measuring scale is calibrated in terms of degrees API; it is calculated as follows: Degrees API = (141.5/sp.gr.60 deg.F/60 deg.F) - 131.5.

Asphalt: A dark brown-to-black cement-like material obtained by petroleum processing and containing bitumens as the predominant component; used primarily for road construction. It includes crude asphalt as well as the following finished products: cements, fluxes, the asphalt content of emulsions (exclusive of water), and petroleum distillates blended with asphalt to make cutback asphalts. Note: The conversion factor for asphalt is 5.5 barrels per short ton.

Associated natural gas: See *Associated-dissolved natural gas* and *Natural gas*.

Associated-dissolved natural gas: Natural gas that occurs in crude oil reservoirs either as free gas (associated) or as gas in solution with crude oil (dissolved gas). See *Natural gas*.

Aviation gasoline (finished): A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in aviation reciprocating engines. Fuel specifications are provided in ASTM Specification D 910 and Military Specification MIL-G-5572. Note: Data on blending components are not counted in data on finished aviation gasoline.

Balancing item: Represents differences between the sum of the components of natural gas supply and the sum of the components of natural gas disposition. These differences may be due to quantities lost or to the effects of data reporting problems. Reporting problems include differences due to the net result of conversions of flow data metered at varying temperature and pressure bases and converted to a standard temperature and pressure base; the effect of variations in company accounting and billing practices; differences between billing cycle and calendar period time frames; and imbalances resulting from the merger of data reporting systems that vary in scope, format, definitions, and type of respondents.

Biofuels: Liquid fuels and blending components produced from biomass (plant) feedstocks, used primarily for transportation.

Biogas: The gas produced from the anaerobic decomposition of organic material in a landfill.

Biogenic: Produced by the actions of living organisms.

Biomass: Organic nonfossil material of biological origin constituting a renewable energy source.

Biosphere: The portion of the Earth and its atmosphere that can support life. The part of the global carbon cycle that includes living organisms and biogenic organic matter.

Bituminous coal: A dense coal, usually black, sometimes dark brown, often with well-defined bands of bright and dull material, used primarily as fuel in steam-electric power generation, with substantial quantities also used for heat and power applications in manufacturing and to make coke. Bituminous coal is the most abundant coal in active U.S. mining regions. Its moisture content usually is less than 20 percent. The heat content of bituminous coal ranges from 21 to 30 million Btu per ton on a moist, mineral-matter-free basis. The heat content of bituminous coal consumed in the United States averages 24 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

BOD_5: The biochemical oxygen demand of wastewater during decomposition occurring over a 5-day period. A measure of the organic content of wastewater.

Bromofluorocarbons (halons): Inert, nontoxic chemicals that have at least one bromine atom in their chemical makeup. They evaporate without leaving a residue and are used in fire extinguishing systems, especially for large computer installations.

Bunker fuel: Fuel supplied to ships and aircraft, both domestic and foreign, consisting primarily of residual and distillate fuel oil for ships and kerosene-based jet fuel for aircraft. The term "international bunker fuels" is used to denote the consumption of fuel for international transport activities. *Note*: For the purposes of greenhouse gas emissions inventories, data on emissions from combustion of international bunker fuels are subtracted from national emissions totals. Historically, bunker fuels have meant only ship fuel. See *Vessel bunkering*.

Calcination: A process in which a material is heated to a high temperature without fusing, so that hydrates, carbonates, or other compounds are decomposed and the volatile material is expelled.

Calcium sulfate: A white crystalline salt, insoluble in water. Used in Keene's cement, in pigments, as a paper filler, and as a drying agent.

Calcium sulfite: A white powder, soluble in dilute sulfuric acid. Used in the sulfite process for the manufacture of wood pulp.

Capital stock: Property, plant and equipment used in the production, processing and distribution of energy resources.

Carbon black: An amorphous form of carbon, produced commercially by thermal or oxidative decomposition of hydrocarbons and used principally in rubber goods, pigments, and printer's ink.

Carbon budget: Carbon budget: The balance of the exchanges (incomes and losses) of carbon between carbon sinks (e.g., atmosphere and biosphere) in the carbon cycle. See *Carbon cycle* and *Carbon sink*.

Carbon cycle: All carbon sinks and exchanges of carbon from one sink to another by various chemical, physical, geological, and biological processes. See *Carbon sink* and *Carbon budget*.

Carbon dioxide (CO_2): A colorless, odorless, nonpoisonous gas that is a normal part of Earth's atmosphere. Carbon dioxide is a product of fossil-fuel combustion as well as other processes. It is considered a greenhouse gas as it traps heat (infrared energy) radiated by the Earth into the atmosphere and thereby contributes to the potential for global warming. The global warming potential (GWP) of other greenhouse gases is measured in relation to that of carbon dioxide, which by international scientific convention is assigned a value of one (1). See *Global warming potential (GWP)* and *Greenhouse gases*.

Carbon dioxide equivalent: The amount of carbon dioxide by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas. Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured (for example, methane) by its estimated global warming potential (which is 21 for methane). "Carbon equivalent units" are defined as carbon dioxide equivalents multiplied by the carbon content of carbon dioxide (i.e., 12/44).

Carbon flux: See *Carbon budget*.

Carbon intensity: The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels. See *Emissions coefficient* and *Carbon output rate*.

Carbon output rate: The amount of carbon by weight per kilowatthour of electricity produced.

Carbon sequestration: The fixation of atmospheric carbon dioxide in a carbon sink through biological or physical processes.

Carbon sink: A reservoir that absorbs or takes up released carbon from another part of the carbon cycle. The four sinks, which are regions of the Earth within which carbon behaves in a systematic manner, are the atmosphere, terrestrial biosphere (usually including freshwater systems), oceans, and sediments (including fossil fuels).

Catalytic converter: A device containing a catalyst for converting automobile exhaust into mostly harmless products.

Catalytic hydrocracking: A refining process that uses hydrogen and catalysts with relatively low temperatures and high pressures for converting middle boiling or residual material to high octane gasoline, reformer charge stock, jet fuel, and/or high grade fuel oil. The process uses one or more catalysts, depending on product output, and can handle high sulfur feedstocks without prior desulfurization.

Cesspool: An underground reservoir for liquid waste, typically household sewage.

Chlorofluorocarbon (CFC): Any of various compounds consisting of carbon, hydrogen, chlorine, and fluorine used as refrigerants. CFCs are now thought to be harmful to the earth's atmosphere.

Clean Development Mechanism (CDM): A Kyoto Protocol program that enables industrialized countries to finance emissions-avoiding projects in developing countries and receive credit for reductions achieved against their own emissions limitation targets. See *Kyoto Protocol*.

Climate: The average course or condition of the weather over a period of years as exhibited by temperature, humidity, wind velocity, and precipitation.

Climate change: A term used to refer to all forms of climatic inconsistency, but especially to significant change from one prevailing climatic condition to another. In some cases, "climate change" has been used synonymously with the term "global warming"; scientists, however, tend to use the term in a wider sense inclusive of natural changes in climate, including climatic cooling.

Clinker: Powdered cement, produced by heating a properly proportioned mixture of finely ground raw materials (calcium carbonate, silica, alumina, and iron oxide) in a kiln to a temperature of about 2,700ºF.

Cloud condensation nuclei: Aerosol particles that provide a platform for the condensation of water vapor, resulting in clouds with higher droplet concentrations and increased albedo.

Coal coke: See *Coke (coal)*.

Coalbed methane: Methane is generated during coal formation and is contained in the coal microstructure. Typical recovery entails pumping water out of the coal to allow the gas to escape. Methane is the principal component of natural gas. Coalbed methane can be added to natural gas pipelines without any special treatment.

Coke (coal): A solid carbonaceous residue derived from low-ash, low-sulfur bituminous coal from which the volatile constituents are driven off by baking in an oven at temperatures as high as 2,000 degrees Fahrenheit so that the fixed carbon and residual ash are fused together. Coke is used as a fuel and as a reducing agent in smelting iron ore in a blast furnace. Coke from coal is grey, hard, and porous and has a heating value of 24.8 million Btu per ton.

Coke (petroleum): A residue high in carbon content and low in hydrogen that is the final product of thermal decomposition in the condensation process in cracking. This product is reported as marketable coke or catalyst coke. The conversion is 5 barrels (of 42 U.S. gallons each) per short ton. Coke from petroleum has a heating value of 6.024 million Btu per barrel.

Combustion: Chemical oxidation accompanied by the generation of light and heat.

Combustion chamber: An enclosed vessel in which chemical oxidation of fuel occurs.

Conference of the Parties (COP): The collection of nations that have ratified the Framework Convention on Climate Change (FCCC). The primary role of the COP is to keep implementation of the FCCC under review and make the decisions necessary for its effective implementation. See *Framework Convention on Climate Change (FCCC)*.

Cracking: The refining process of breaking down the larger, heavier, and more complex hydrocarbon molecules into simpler and lighter molecules.

Criteria pollutant: A pollutant determined to be hazardous to human health and regulated under EPA's National Ambient Air Quality Standards. The 1970 amendments to the Clean Air Act require EPA to describe the health and welfare impacts of a pollutant as the "criteria" for inclusion in the regulatory regime.

Crop residue: Organic residue remaining after the harvesting and processing of a crop.

Cultivar: A horticulturally or agriculturally derived variety of a plant.

Deforestation: The net removal of trees from forested land.

Degasification system: The methods employed for removing methane from a coal seam that could not otherwise be removed by standard ventilation fans and thus would pose a substantial hazard to coal miners. These systems may be used prior to mining or during mining activities.

Degradable organic carbon: The portion of organic carbon present in such solid waste as paper, food waste, and yard waste that is susceptible to biochemical decomposition.

Desulfurization: The removal of sulfur, as from molten metals, petroleum oil, or flue gases.

Diffusive transport: The process by which particles of liquids or gases move from an area of higher concentration to an area of lower concentration.

Distillate fuel: A general classification for one of the petroleum fractions produced in conventional distillation operations. It includes diesel fuels and fuel oils. Products known as No. 1, No. 2, and No. 4 diesel fuel are used in on-highway diesel engines, such as those in trucks and automobiles, as well as off-highway engines, such as those in railroad locomotives and agricultural machinery. Products known as No. 1, No. 2, and No. 4 fuel oils are used primarily for space heating and electric power generation.

Efflux: An outward flow.

Electrical generating capacity: The full-load continuous power rating of electrical generating facilities, generators, prime movers, or other electric equipment (individually or collectively).

EMCON Methane Generation Model: A model for estimating the production of methane from municipal solid waste landfills.

Emissions: Anthropogenic releases of gases to the atmosphere. In the context of global climate change, they consist of radiatively important greenhouse gases (e.g., the release of carbon dioxide during fuel combustion).

Emissions coefficient: A unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., pounds of carbon dioxide emitted per Btu of fossil fuel consumed).

Enteric fermentation: A digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream of an animal.

Eructation: An act or instance of belching.

ETBE (ethyl tertiary butyl ether): $(CH_3)_3COC_2H$: An oxygenate blend stock formed by the catalytic etherification of isobutylene with ethanol.

Ethylene: An olefinic hydrocarbon recovered from refinery processes or petrochemical processes. Ethylene is used as a petrochemical feedstock for numerous chemical applications and the production of consumer goods.

Ethylene dichloride: A colorless, oily liquid used as a solvent and fumigant for organic synthesis, and for ore flotation.

Facultative bacteria: Bacteria that grow equally well under aerobic and anaerobic conditions.

Flange: A rib or a rim for strength, for guiding, or for attachment to another object (e.g., on a pipe).

Flared: Gas disposed of by burning in flares usually at the production sites or at gas processing plants.

Flatus: Gas generated in the intestines or the stomach of an animal.

Flue gas desulfurization: Equipment used to remove sulfur oxides from the combustion gases of a boiler plant before discharge to the atmosphere. Also referred to as scrubbers. Chemicals such as lime are used as scrubbing media.

Fluidized-bed combustion: A method of burning particulate fuel, such as coal, in which the amount of air required for combustion far exceeds that found in conventional burners. The fuel particles are continually fed into a bed of mineral ash in the proportions of 1 part fuel to 200 parts ash, while a flow of air passes up through the bed, causing it to act like a turbulent fluid.

Flux material: A substance used to promote fusion, e.g., of metals or minerals.

Fodder: Coarse food for domestic livestock.

Forestomach: See *Rumen*.

Fossil fuel: An energy source formed in the earths crust from decayed organic material. The common fossil fuels are petroleum, coal, and natural gas.

Framework Convention on Climate Change (FCCC): An agreement opened for signature at the "Earth Summit" in Rio de Janeiro, Brazil, on June 4, 1992, which has the goal of stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent significant anthropogenically forced climate change. See *Climate change*.

Fuel cycle: The entire set of sequential processes or stages involved in the utilization of fuel, including extraction, transformation, transportation, and combustion. Emissions generally occur at each stage of the fuel cycle.

Fugitive emissions: Unintended leaks of gas from the processing, transmission, and/or transportation of fossil fuels.

Gasification: A method for converting coal, petroleum, biomass, wastes, or other carbon-containing materials into a gas that can be burned to generate power or processed into chemicals and fuels.

Gate station: Location where the pressure of natural gas being transferred from the transmission system to the distribution system is lowered for transport through small diameter, low pressure pipelines.

Geothermal: Pertaining to heat within the Earth.

Global climate change: See *Climate change*.

Global warming: An increase in the near surface temperature of the Earth. Global warming has occurred in the distant past as the result of natural influences, but the term is today most often used to refer to the warming that some scientists predict will occur as a result of increased anthropogenic emissions of greenhouse gases. See *Climate change*.

Global warming potential (GWP): An index used to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emission of one kilogram of a greenhouse gas to that from the emission of one kilogram of carbon dioxide over a fixed period of time, such as 100 years.

Greenhouse effect: The result of water vapor, carbon dioxide, and other atmospheric gases trapping radiant (infrared) energy, thereby keeping the earth's surface warmer than it would otherwise be. Greenhouse gases within the lower levels of the atmosphere trap this radiation, which would otherwise escape into space, and subsequent re-radiation of some of this energy back to the Earth maintains higher surface temperatures than would occur if the gases were absent. See *Greenhouse gases*.

Greenhouse gases: Those gases, such as water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride, that are transparent to solar (short-wave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving the Earth's atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface.

Gross gas withdrawal: The full-volume of compounds extracted at the wellhead, including nonhydrocarbon gases and natural gas plant liquids.

Gypsum: Calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), a sludge constituent from the conventional lime scrubber process, obtained as a byproduct of the dewatering operation and sold for commercial use.

Halogenated substances: A volatile compound containing halogens, such as chlorine, fluorine or bromine.

Halons: See *Bromofluorocarbons*.

Heating degree-days (HDD): A measure of how cold a location is over a period of time relative to a base temperature, most commonly specified as 65 degrees Fahrenheit. The measure is computed for each day by subtracting the average of the day's high and low temperatures from the base temperature (65 degrees), with negative values set equal to zero. Each day's heating degree-days are summed to create a heating degree-day measure for a specified reference period. Heating degree-days are used in energy analysis as an indicator of space heating energy requirements or use.

Herbivore: A plant-eating animal.

Hydrocarbon: An organic chemical compound of hydrogen and carbon in either gaseous, liquid, or solid phase. The molecular structure of hydrocarbon compounds varies from the simple (e.g., methane, a constituent of natural gas) to the very heavy and very complex.

Hydrochlorofluorocarbons (HCFCs): Chemicals composed of one or more carbon atoms and varying numbers of hydrogen, chlorine, and fluorine atoms.

Hydrofluorocarbons (HFCs): A group of man-made chemicals composed of one or two carbon atoms and varying numbers of hydrogen and fluorine atoms. Most HFCs have 100-year Global Warming Potentials in the thousands.

Hydroxyl radical (OH): An important chemical scavenger of many trace gases in the atmosphere that are greenhouse gases. Atmospheric concentrations of OH affect the atmospheric lifetimes of greenhouse gases, their abundance, and, ultimately, the effect they have on climate.

Intergovernmental Panel on Climate Change (IPCC): A panel established jointly in 1988 by the World Meteorological Organization and the United Nations Environment Program to assess the scientific information relating to climate change and to formulate realistic response strategies.

International bunker fuels: See *Bunker fuels*.

Jet fuel: A refined petroleum product used in jet aircraft engines. It includes kerosene-type jet fuel and naphtha-type jet fuel.

Joint Implementation (JI): Agreements made between two or more nations under the auspices of the Framework Convention on Climate Change (FCCC) whereby a developed country can receive "emissions reduction units" when it helps to finance projects that reduce net emissions in another developed country (including countries with economies in transition).

Kerosene: A light petroleum distillate that is used in space heaters, cook stoves, and water heaters and is suitable for use as a light source when burned in wick-fed lamps. Kerosene has a maximum distillation temperature of 400 degrees Fahrenheit at the 10-percent recovery point, a final boiling point of 572 degrees Fahrenheit, and a minimum flash point of 100 degrees Fahrenheit. Included are No. 1-K and No. 2-K, the two grades recognized by ASTM Specification D 3699 as well as all other grades of kerosene called range or stove oil, which have properties similar to those of No. 1 fuel oil. See *Kerosene-type jet fuel*.

Kerosene-type jet fuel: A kerosene-based product having a maximum distillation temperature of 400 degrees Fahrenheit at the 10-percent recovery point and a final maximum boiling point of 572 degrees Fahrenheit and meeting ASTM Specification D 1655 and Military Specifications MIL-T-5624P and MIL-T-83133D (Grades JP-5 and JP-8). It is used for commercial and military turbojet and turboprop aircraft engines.

Kyoto Protocol: The result of negotiations at the third Conference of the Parties (COP-3) in Kyoto, Japan, in December of 1997. The Kyoto Protocol sets binding greenhouse gas emissions targets for countries that sign and ratify the agreement. The gases covered under the Protocol include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride.

Ketone-alcohol (cyclohexanol): An oily, colorless, hygroscopic liquid with a camphor-like odor. Used in soapmaking, dry cleaning, plasticizers, insecticides, and germicides.

Leachate: The liquid that has percolated through the soil or other medium.

Lignite: The lowest rank of coal, often referred to as brown coal, used almost exclusively as fuel for steam-electric power generation. It is brownish-black and has a high inherent moisture content, sometimes as high as 45 percent The heat content of lignite ranges from 9 to 17 million Btu per ton on a moist, mineral-matter-free basis. The heat content of lignite consumed in the United States averages 13 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

Liquefied petroleum gases: A group of hydrocarbon-based gases derived from crude oil refining or natural gas fractionation. They include ethane, ethylene, propane, propylene, normal butane, butylene, isobutane, and isobutylene. For convenience of transportation, these gases are liquefied through pressurization.

Lubricants: Substances used to reduce friction between bearing surfaces, or incorporated into other materials used as processing aids in the manufacture of other products, or used as carriers of other materials. Petroleum lubricants may be produced either from distillates or residues. Lubricants include all grades of lubricating oils, from spindle oil to cylinder oil to those used in greases.

Methane: A colorless, flammable, odorless hydrocarbon gas (CH4) which is the major component of natural gas. It is also an important source of hydrogen in various industrial processes. Methane is a greenhouse gas. See also *Greenhouse gases*.

Methanogens: Bacteria that synthesize methane, requiring completely anaerobic conditions for growth.

Methanol: A light alcohol that can be used for gasoline blending. See oxygenate.

Methanotrophs: Bacteria that use methane as food and oxidize it into carbon dioxide.

Methyl chloroform (trichloroethane): An industrial chemical (CH_3CCl_3) used as a solvent, aerosol propellant, and pesticide and for metal degreasing.

Methyl tertiary butyl ether (MTBE): A colorless, flammable, liquid oxygenated hydrocarbon containing 18.15 percent oxygen.

Methylene chloride: A colorless liquid, nonexplosive and practically nonflammable. Used as a refrigerant in centrifugal compressors, a solvent for organic materials, and a component in nonflammable paint removers.

Mole: The quantity of a compound or element that has a weight in grams numerically equal to its molecular weight. Also referred to as gram molecule or gram molecular weight.

Montreal Protocol: The Montreal Protocol on Substances that Deplete the Ozone Layer (1987). An international agreement, signed by most of the industrialized nations, to substantially reduce the use of chlorofluorocarbons (CFCs). Signed in January 1989, the original document called for a 50-percent reduction in CFC use by 1992 relative to 1986 levels. The subsequent London Agreement called for a complete elimination of CFC use by 2000. The Copenhagen Agreement, which called for a

complete phaseout by January 1, 1996, was implemented by the U.S. Environmental Protection Agency.

Motor gasoline (finished): A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in spark-ignition engines. Motor gasoline, as defined in ASTM Specification D 4814 or Federal Specification VV-G-1690C, is characterized as having a boiling range of 122 to 158 degrees Fahrenheit at the 10 percent recovery point to 365 to 374 degrees Fahrenheit at the 90 percent recovery point. "Motor Gasoline" includes conventional gasoline; all types of oxygenated gasoline, including gasohol; and reformulated gasoline, but excludes aviation gasoline. Note: Volumetric data on blending components, such as oxygenates, are not counted in data on finished motor gasoline until the blending components are blended into the gasoline.

Multiple cropping: A system of growing several crops on the same field in one year.

Municipal solid waste: Residential solid waste and some nonhazardous commercial, institutional, and industrial wastes.

Naphtha less than 401 degrees Fahrenheit: A naphtha with a boiling range of less than 401 degrees Fahrenheit that is intended for use as a petrochemical feedstock. Also see *Petrochemical feedstocks*.

Naphtha-type jet fuel: A fuel in the heavy naphtha boiling range having an average gravity of 52.8 degrees API, 20 to 90 percent distillation temperatures of 290 degrees to 470 degrees Fahrenheit, and meeting Military Specification MIL-T-5624L (Grade JP-4). It is used primarily for military turbojet and turboprop aircraft engines because it has a lower freeze point than other aviation fuels and meets engine requirements at high altitudes and speeds.

Natural gas: A mixture of hydrocarbons and small quantities of various nonhydrocarbons in the gaseous phase or in solution with crude oil in natural underground reservoirs.

Natural gas liquids (NGLs): Those hydrocarbons in natural gas that are separated as liquids from the gas. Includes natural gas plant liquids and lease condensate.

Natural gas, pipeline quality: A mixture of hydrocarbon compounds existing in the gaseous phase with sufficient energy content, generally above 900 Btu, and a small enough share of impurities for transport through commercial gas pipelines and sale to end-users.

Nitrogen oxides (NO_x): Compounds of nitrogen and oxygen produced by the burning of fossil fuels.

Nitrous oxide (N_2O): A colorless gas, naturally occurring in the atmosphere. Nitrous oxide has a 100-year Global Warming Potential of 310.

Nonmethane volatile organic compounds (NMVOCs): Organic compounds, other than methane, that participate in atmospheric photochemical reactions.

Octane: A flammable liquid hydrocarbon found in petroleum. Used as a standard to measure the antiknock properties of motor fuel.

Oil reservoir: An underground pool of liquid consisting of hydrocarbons, sulfur, oxygen, and nitrogen trapped within a geological formation and protected from evaporation by the overlying mineral strata.

Organic content: The share of a substance that is of animal or plant origin.

Organic waste: Waste material of animal or plant origin.

Oxidize: To chemically transform a substance by combining it with oxygen.

Oxygenates: Substances which, when added to gasoline, increase the amount of oxygen in that gasoline blend. Ethanol, Methyl Tertiary Butyl Ether (MTBE), Ethyl Tertiary Butyl Ether (ETBE), and methanol are common oxygenates.

Ozone: A molecule made up of three atoms of oxygen. Occurs naturally in the stratosphere and provides a protective layer shielding the Earth from harmful ultraviolet radiation. In the troposphere, it is a chemical oxidant, a greenhouse gas, and a major component of photochemical smog.

Ozone precursors: Chemical compounds, such as carbon monoxide, methane, nonmethane hydrocarbons, and nitrogen oxides, which in the presence of solar radiation react with other chemical compounds to form ozone.

Paraffinic hydrocarbons: Straight-chain hydrocarbon compounds with the general formula C_nH_{2n+2}.

Perfluorocarbons (PFCs): A group of man-made chemicals composed of one or two carbon atoms and four to six fluorine atoms, containing no chlorine. PFCs have no commercial uses and are emitted as a byproduct of aluminum smelting and semiconductor manufacturing. PFCs have very high 100-year Global Warming Potentials and are very long-lived in the atmosphere.

Perfluoromethane: A compound (CF_4) emitted as a byproduct of aluminum smelting.

Petrochemical feedstocks: Chemical feedstocks derived from petroleum principally for the manufacture of chemicals, synthetic rubber, and a variety of plastics.

Petroleum: A broadly defined class of liquid hydrocarbon mixtures. Included are crude oil, lease condensate, unfinished oils, refined products obtained from the processing of crude oil, and natural gas plant liquids. Note: Volumes of finished petroleum products include nonhydrocarbon compounds, such as additives and detergents, after they have been blended into the products.

Petroleum coke: See *Coke (petroleum)*.

Photosynthesis: The manufacture by plants of carbohydrates and oxygen from carbon dioxide and water in the presence of chlorophyll, with sunlight as the energy source. Carbon is sequestered and oxygen and water vapor are released in the process.

Pig iron: Crude, high-carbon iron produced by reduction of iron ore in a blast furnace.

Pipeline, distribution: A pipeline that conveys gas from a transmission pipeline to its ultimate consumer.

Pipeline, gathering: A pipeline that conveys gas from a production well/field to a gas processing plant or transmission pipeline for eventual delivery to end-use consumers.

Pipeline, transmission: A pipeline that conveys gas from a region where it is produced to a region where it is to be distributed.

Planetary albedo: The fraction of incident solar radiation that is reflected by the Earth-atmosphere system and returned to space, mostly by backscatter from clouds in the atmosphere.

Pneumatic device: A device moved or worked by air pressure.

Polystyrene: A polymer of styrene that is a rigid, transparent thermoplastic with good physical and electrical insulating properties, used in molded products, foams, and sheet materials.

Polyvinyl chloride (PVC): A polymer of vinyl chloride. Tasteless. odorless, insoluble in most organic solvents. A member of the family vinyl resin, used in soft flexible films for food packaging and in molded rigid products, such as pipes, fibers, upholstery, and bristles.

Post-mining emissions: Emissions of methane from coal occurring after the coal has been mined, during transport or pulverization.

Radiative forcing: A change in average net radiation at the top of the troposphere (known as the tropopause) because of a change in either incoming solar or exiting infrared radiation. A positive radiative forcing tends on average to warm the earth's surface; a negative radiative forcing on average tends to cool the earth's surface. Greenhouse gases, when emitted into the atmosphere, trap infrared energy radiated from the earth's surface and therefore tend to produce positive radiative forcing. See *Greenhouse gases*.

Radiatively active gases: Gases that absorb incoming solar radiation or outgoing infrared radiation, affecting the vertical temperature profile of the atmosphere. See *Radiative forcing*.

Ratoon crop: A crop cultivated from the shoots of a perennial plant.

Redox potential: A measurement of the state of oxidation of a system.

Reflectivity: The ratio of the energy carried by a wave after reflection from a surface to its energy before reflection.

Reforestation: Replanting of forests on lands that have recently been harvested or otherwise cleared of trees.

Reformulated gasoline: Finished motor gasoline formulated for use in motor vehicles, the composition and properties of which meet the requirements of the reformulated gasoline regulations promulgated by the U.S. Environmental Protection Agency under Section 211(k) of the Clean Air Act. Note: This category includes oxygenated fuels program reformulated gasoline (OPRG) but excludes reformulated gasoline blendstock for oxygenate blending (RBOB).

Renewable energy resources: Energy resources that are naturally replenishing but flow-limited. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include: biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action.

Residual fuel oil: A general classification for the heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations. It conforms to ASTM Specifications D 396 and D 975 and Federal Specification VV-F-815C. No. 5, a residual fuel oil of medium viscosity, is also known as Navy Special and is defined in Military Specification MIL-F-859E, including Amendment 2 (NATO Symbol F-770). It is used in steam-powered vessels in government service and inshore powerplants. No. 6 fuel oil includes Bunker C fuel oil and is used for the production of electric power, space heating, vessel bunkering, and various industrial purposes.

Rumen: The large first compartment of the stomach of certain animals in which cellulose is broken down by the action of bacteria.

Sample: A set of measurements or outcomes selected from a given population.

Sequestration: See *Carbon sequestration*.

Septic tank: A tank in which the solid matter of continuously flowing sewage is disintegrated by bacteria.

Sinter: A chemical sedimentary rock deposited by precipitation from mineral waters, especially siliceous sinter and calcareous sinter.

Sodium silicate: A grey-white powder soluble in alkali and water, insoluble in alcohol and acid. Used to fireproof textiles, in petroleum refining and corrugated paperboard manufacture, and as an egg preservative. Also referred to as liquid gas, silicate of soda, sodium metasilicate, soluble glass, and water glass.

Sodium tripolyphosphate: A white powder used for water softening and as a food additive and texturizer.

Stabilization lagoon: A shallow artificial pond used for the treatment of wastewater. Treatment includes removal of solid material through sedimentation, the decomposition of organic material by bacteria, and the removal of nutrients by algae.

Still gas (refinery gas): Any form or mixture of gases produced in refineries by distillation, cracking, reforming, and other processes. The principal constituents are methane, ethane, ethylene, normal butane, butylene, propane, propylene, etc. Still gas is used as a refinery fuel and a petrochemical feedstock. The conversion factor is 6 million Btu per fuel oil equivalent barrel.

Stratosphere: The region of the upper atmosphere extending from the tropopause (8 to 15 kilometers altitude) to about 50 kilometers. Its thermal structure, which is determined by its radiation balance, is generally very stable with low humidity.

Stripper well: An oil or gas well that produces at relatively low rates. For oil, stripper production is usually defined as production rates of between 5 and 15 barrels of oil per day. Stripper gas production would generally be anything less than 60 thousand cubic feet per day.

Styrene: A colorless, toxic liquid with a strong aromatic aroma. Insoluble in water, soluble in alcohol and ether; polymerizes rapidly; can become explosive. Used to make polymers and copolymers, polystyrene plastics, and rubber.

Subbituminous coal: A coal whose properties range from those of lignite to those of bituminous coal and used primarily as fuel for steam-electric power generation. It may be dull, dark brown to black, soft and crumbly, at the lower end of the range, to bright, jet black, hard, and relatively strong, at the upper end. Subbituminous coal contains 20 to 30 percent inherent moisture by weight. The heat content of subbituminous coal ranges from 17 to 24 million Btu per ton on a moist, mineral-matter-free basis. The heat content of subbituminous coal consumed in the United States averages 17 to 18 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

Sulfur dioxide (SO_2): A toxic, irritating, colorless gas soluble in water, alcohol, and ether. Used as a chemical intermediate, in paper pulping and ore refining, and as a solvent.

Sulfur hexafluoride (SF_6): A colorless gas soluble in alcohol and ether, and slightly less soluble in water. It is used as a dielectric in electronics. It possesses the highest 100-year Global Warming Potential of any gas (23,900).

Sulfur oxides (SO_x): Compounds containing sulfur and oxygen, such as sulfur dioxide (SO_2) and sulfur trioxide (SO_3).

Tertiary amyl methyl ether ($(CH_3)_2(C_2H_5)COCH_3$): An oxygenate blend stock formed by the catalytic etherification of isoamylene with methanol.

Troposphere: The inner layer of the atmosphere below about 15 kilometers, within which there is normally a steady decrease of temperature with increasing altitude. Nearly all clouds form and weather conditions manifest themselves within this region. Its thermal structure is caused primarily by the heating of the earth's surface by solar radiation, followed by heat transfer through turbulent mixing and convection.

Uncertainty: A measure used to quantify the plausible maximum and minimum values for emissions from any source, given the biases inherent in the methods used to calculate a point estimate and known sources of error.

Vapor displacement: The release of vapors that had previously occupied space above liquid fuels stored in tanks. These releases occur when tanks are emptied and filled.

Ventilation system: A method for reducing methane concentrations in coal mines to non-explosive levels by blowing air across the mine face and using large exhaust fans to remove methane while mining operations proceed.

Vessel bunkering: Includes sales for the fueling of commercial or private boats, such as pleasure craft, fishing boats, tugboats, and ocean-going vessels, including vessels operated by oil companies. Excluded are volumes sold to the U.S. Armed Forces.

Volatile organic compounds (VOCs): Organic compounds that participate in atmospheric photochemical reactions.

Volatile solids: A solid material that is readily decomposable at relatively low temperatures.

Waste flow: Quantity of a waste stream generated by an activity.

Wastewater: Water that has been used and contains dissolved or suspended waste materials.

Wastewater, domestic and commercial: Wastewater (sewage) produced by domestic and commercial establishments.

Wastewater, industrial: Wastewater produced by industrial processes.

Water vapor: Water in a vaporous form, especially when below boiling temperature and diffused (e.g., in the atmosphere).

Wax: A solid or semi-solid material derived from petroleum distillates or residues by such treatments as chilling, precipitating with a solvent, or de-oiling. It is a light-colored, more-or-less translucent crystalline mass, slightly greasy to the touch, consisting of a mixture of solid hydrocarbons in which the paraffin series predominates. Includes all marketable wax, whether crude scale or fully refined. The three grades included are microcrystalline, crystalline-fully refined, and crystalline-other. The conversion factor is 280 pounds per 42 U.S. gallons per barrel.

Weanling system: A cattle management system that places calves on feed starting at 165 days of age and continues until the animals have reached slaughter weight.

Wellhead: The point at which the crude (and/or natural gas) exits the ground. Following historical precedent, the volume and price for crude oil production are labeled as "wellhead," even though the cost and volume are now generally measured at the lease boundary. In the context of domestic crude price data, the term "wellhead" is the generic term used to reference the production site or lease property.

Wetlands: Areas regularly saturated by surface or groundwater and subsequently characterized by a prevalence of vegetation adapted for life in saturated-soil conditions.

Wood energy: Wood and wood products used as fuel, including roundwood (cordwood), limbwood, wood chips, bark, sawdust, forest residues, charcoal, pulp waste, and spent pulping liquor..

Yearling system: A cattle management system that includes a stocker period from 165 days of age to 425 days of age followed by a 140-day feedlot period.

EXHIBIT G

Climate Change 2007:
Synthesis Report

Synthesis Report

An Assessment of the Intergovernmental Panel on Climate Change

This underlying report, adopted section by section at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

Based on a draft prepared by:

Core Writing Team

Lenny Bernstein, Peter Bosch, Osvaldo Canziani, Zhenlin Chen, Renate Christ, Ogunlade Davidson, William Hare, Saleemul Huq, David Karoly, Vladimir Kattsov, Zbigniew Kundzewicz, Jian Liu, Ulrike Lohmann, Martin Manning, Taroh Matsuno, Bettina Menne, Bert Metz, Monirul Mirza, Neville Nicholls, Leonard Nurse, Rajendra Pachauri, Jean Palutikof, Martin Parry, Dahe Qin, Nijavalli Ravindranath, Andy Reisinger, Jiawen Ren, Keywan Riahi, Cynthia Rosenzweig, Matilde Rusticucci, Stephen Schneider, Youba Sokona, Susan Solomon, Peter Stott, Ronald Stouffer, Taishi Sugiyama, Rob Swart, Dennis Tirpak, Coleen Vogel, Gary Yohe

Extended Writing Team

Terry Barker

Review Editors

Abdelkader Allali, Roxana Bojariu, Sandra Diaz, Ismail Elgizouli, Dave Griggs, David Hawkins, Olav Hohmeyer, Bubu Pateh Jallow, Lučka Kajfež-Bogataj, Neil Leary, Hoesung Lee, David Wratt

Introduction

Introduction

This Synthesis Report is based on the assessment carried out by the three Working Groups (WGs) of the Intergovernmental Panel on Climate Change (IPCC). It provides an integrated view of climate change as the final part of the IPCC's Fourth Assessment Report (AR4).

Topic 1 summarises observed changes in climate and their effects on natural and human systems, regardless of their causes, while Topic 2 assesses the causes of the observed changes. Topic 3 presents projections of future climate change and related impacts under different scenarios.

Topic 4 discusses adaptation and mitigation options over the next few decades and their interactions with sustainable development. Topic 5 assesses the relationship between adaptation and mitigation on a more conceptual basis and takes a longer-term perspective. Topic 6 summarises the major robust findings and remaining key uncertainties in this assessment.

A schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages, is shown in Figure I.1. At the time of the Third Assessment Report (TAR) in 2001, information was mainly available to describe the linkages clockwise, i.e. to derive climatic changes and impacts from socio-economic information and emissions. With increased understanding of these linkages, it is now possible to assess the linkages also counterclockwise, i.e. to evaluate possible development pathways and global emissions constraints that would reduce the risk of future impacts that society may wish to avoid.

Schematic framework of anthropogenic climate change drivers, impacts and responses

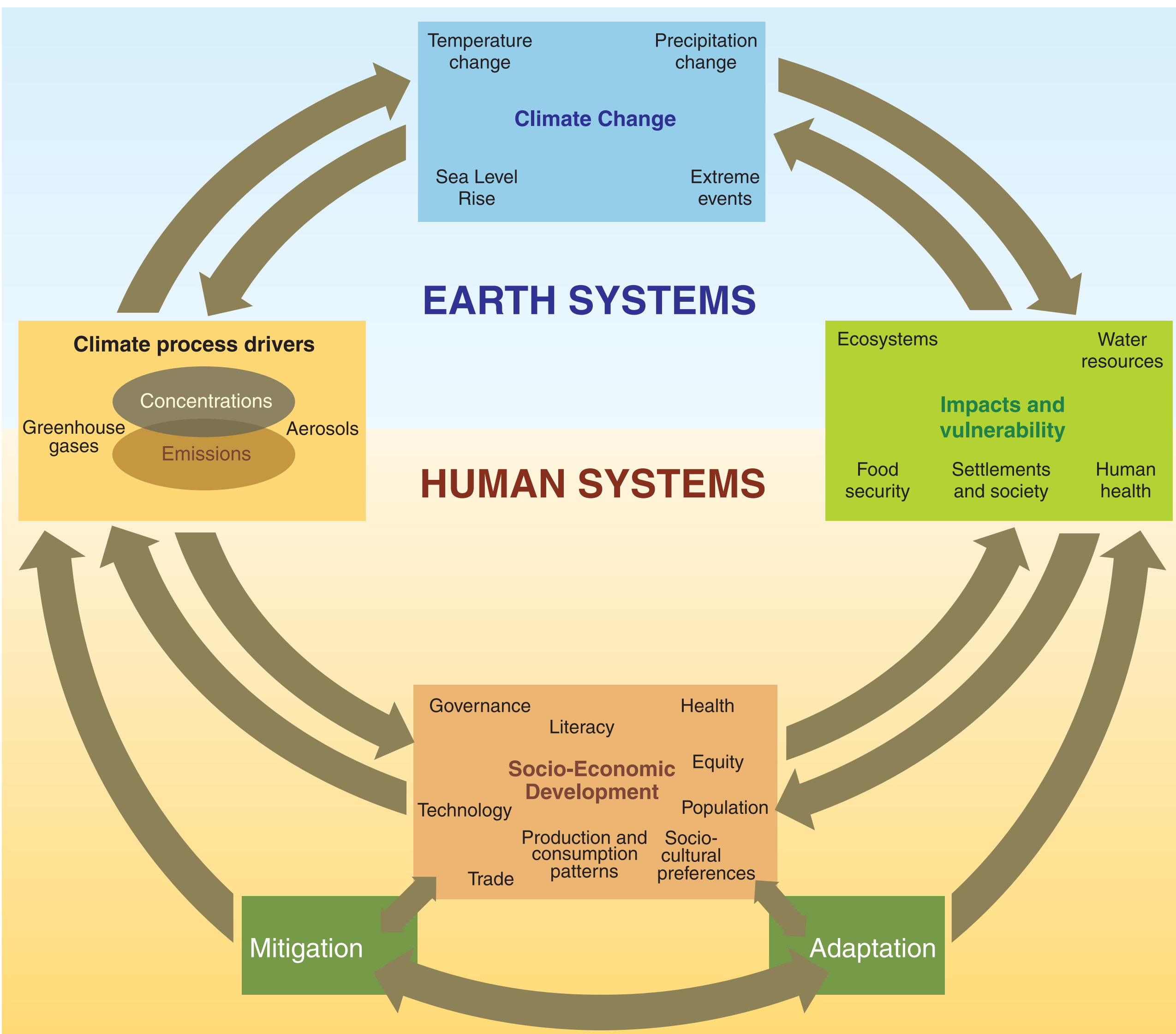


Figure I.1. Schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages.

Treatment of uncertainty

The IPCC uncertainty guidance note[1] defines a framework for the treatment of uncertainties across all WGs and in this Synthesis Report. This framework is broad because the WGs assess material from different disciplines and cover a diversity of approaches to the treatment of uncertainty drawn from the literature. The nature of data, indicators and analyses used in the natural sciences is generally different from that used in assessing technology development or the social sciences. WG I focuses on the former, WG III on the latter, and WG II covers aspects of both.

Three different approaches are used to describe uncertainties each with a distinct form of language. Choices among and within these three approaches depend on both the nature of the information available and the authors' expert judgment of the correctness and completeness of current scientific understanding.

Where uncertainty is assessed qualitatively, it is characterised by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models indicating whether a belief or proposition is true or valid) and the degree of agreement (that is, the level of concurrence in the literature on a particular finding). This approach is used by WG III through a series of self-explanatory terms such as: *high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence; etc.*

Where uncertainty is assessed more quantitatively using expert judgement of the correctness of underlying data, models or analyses, then the following scale of confidence levels is used to express the assessed chance of a finding being correct: v*ery high confidence* at least 9 out of 10; *high confidence* about 8 out of 10; *medium confidence* about 5 out of 10; *low confidence* about 2 out of 10; and *very low confidence* less than 1 out of 10.

Where uncertainty in specific outcomes is assessed using expert judgment and statistical analysis of a body of evidence (e.g. observations or model results), then the following likelihood ranges are used to express the assessed probability of occurrence: *virtually certain* >99%; *extremely likely* >95%; *very likely* >90%; *likely* >66%; *more likely than not* > 50%; *about as likely as not* 33% to 66%; *unlikely* <33%; *very unlikely* <10%; *extremely unlikely* <5%; *exceptionally unlikely* <1%.

WG II has used a combination of confidence and likelihood assessments and WG I has predominantly used likelihood assessments.

This Synthesis Report follows the uncertainty assessment of the underlying WGs. Where synthesised findings are based on information from more than one WG, the description of uncertainty used is consistent with that for the components drawn from the respective WG reports.

Unless otherwise stated, numerical ranges given in square brackets in this report indicate 90% uncertainty intervals (i.e. there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range). Uncertainty intervals are not necessarily symmetric around the best estimate.

[1] See http://www.ipcc.ch/meetings/ar4-workshops-express-meetings/uncertainty-guidance-note.pdf

1

Observed changes in climate and their effects

1.1 Observations of climate change

Since the TAR, progress in understanding how climate is changing in space and time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties and a wider variety of measurements. *{WGI SPM}*

Definitions of climate change

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (Figure 1.1). ***{WGI 3.2, 4.8, 5.2, 5.5, SPM}***

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the TAR (Figure 1.1). The linear warming trend over the 50 years from 1956 to 2005 (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the 100 years from 1906 to 2005. *{WGI 3.2, SPM}*

The temperature increase is widespread over the globe and is greater at higher northern latitudes (Figure 1.2). Average Arctic temperatures have increased at almost twice the global average rate in the past 100 years. Land regions have warmed faster than the oceans (Figures 1.2 and 2.5). Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000m and that the ocean has been taking up over 80% of the heat being added to the climate system. New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates similar to those observed in surface temperature. *{WGI 3.2, 3.4, 5.2, SPM}*

Increases in sea level are consistent with warming (Figure 1.1). Global average sea level rose at an average rate of 1.8 [1.3 to 2.3]mm per year over 1961 to 2003 and at an average rate of about 3.1 [2.4 to 3.8]mm per year from 1993 to 2003. Whether this faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-term trend is unclear. Since 1993 thermal expansion of the oceans has contributed about 57% of the sum of the estimated individual contributions to the sea level rise, with decreases in glaciers and ice caps contributing about 28% and losses from the polar ice sheets contributing the remainder. From 1993 to 2003 the sum of these climate contributions is consistent within uncertainties with the total sea level rise that is directly observed. *{WGI 4.6, 4.8, 5.5, SPM, Table SPM.1}*

Observed decreases in snow and ice extent are also consistent with warming (Figure 1.1). Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres. The maximum areal extent of seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with decreases in spring of up to 15%. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic by up to 3°C. *{WGI 3.2, 4.5, 4.6, 4.7, 4.8, 5.5, SPM}*

At continental, regional and ocean basin scales, numerous long-term changes in other aspects of climate have also been observed. Trends from 1900 to 2005 have been observed in precipitation amount in many large regions. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has *likely*[2] increased since the 1970s. *{WGI 3.3, 3.9, SPM}*

Some extreme weather events have changed in frequency and/or intensity over the last 50 years:

- It is *very likely* that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. *{WGI 3.8, SPM}*
- It is *likely* that heat waves have become more frequent over most land areas. *{WGI 3.8, SPM}*
- It is *likely* that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas. *{WGI 3.8, 3.9, SPM}*
- It is *likely* that the incidence of extreme high sea level[3] has increased at a broad range of sites worldwide since 1975. *{WGI 5.5, SPM}*

There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, and suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. *{WGI 3.8, SPM}*

Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. *{WGI 6.6, SPM}*

[2] Likelihood and confidence statements in italics represent calibrated expressions of uncertainty and confidence. See Box 'Treatment of uncertainty' in the Introduction for an explanation of these terms.

[3] Excluding tsunamis, which are not due to climate change. Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

Changes in temperature, sea level and Northern Hemisphere snow cover

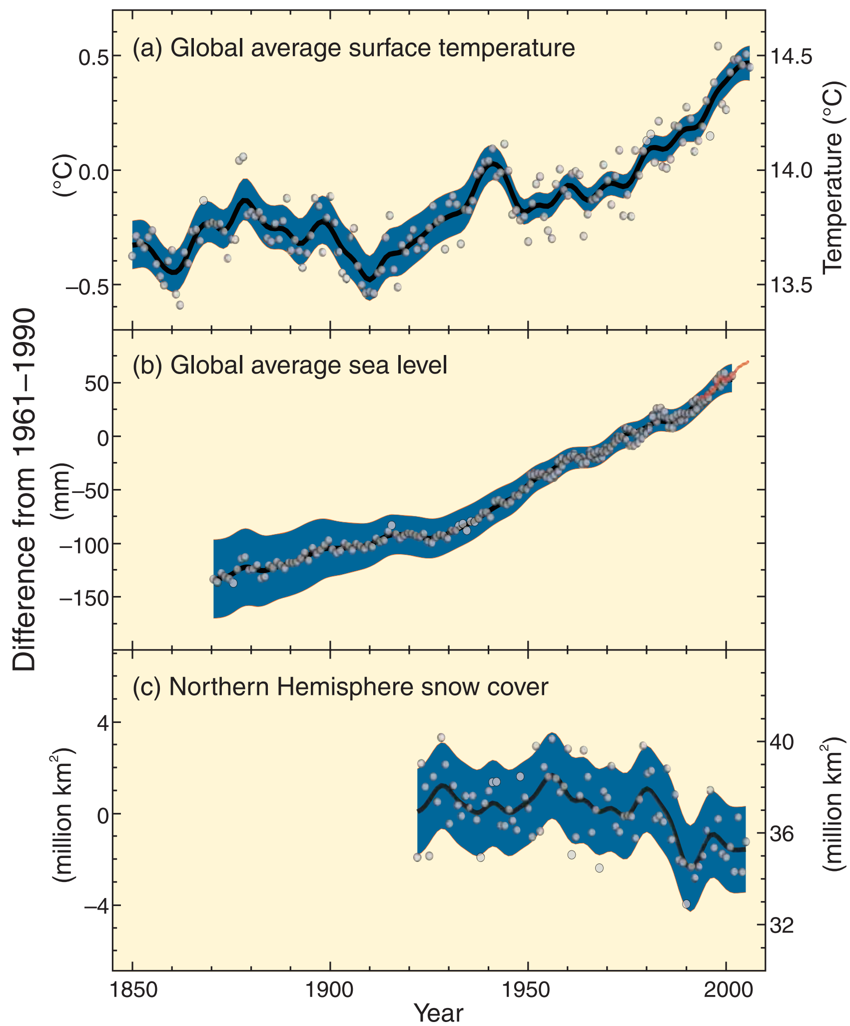


Figure 1.1. *Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {WGI FAQ 3.1 Figure 1, Figure 4.2, Figure 5.13, Figure SPM.3}*

1.2 Observed effects of climate changes

The statements presented here are based largely on data sets that cover the period since 1970. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the TAR. The quality of the data sets has also improved. There is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. *{WGII SPM}*

These studies have allowed a broader and more confident assessment of the relationship between observed warming and impacts than was made in the TAR. That assessment concluded that "there is *high confidence*[2] that recent regional changes in temperature have had discernible impacts on physical and biological systems". *{WGII SPM}*

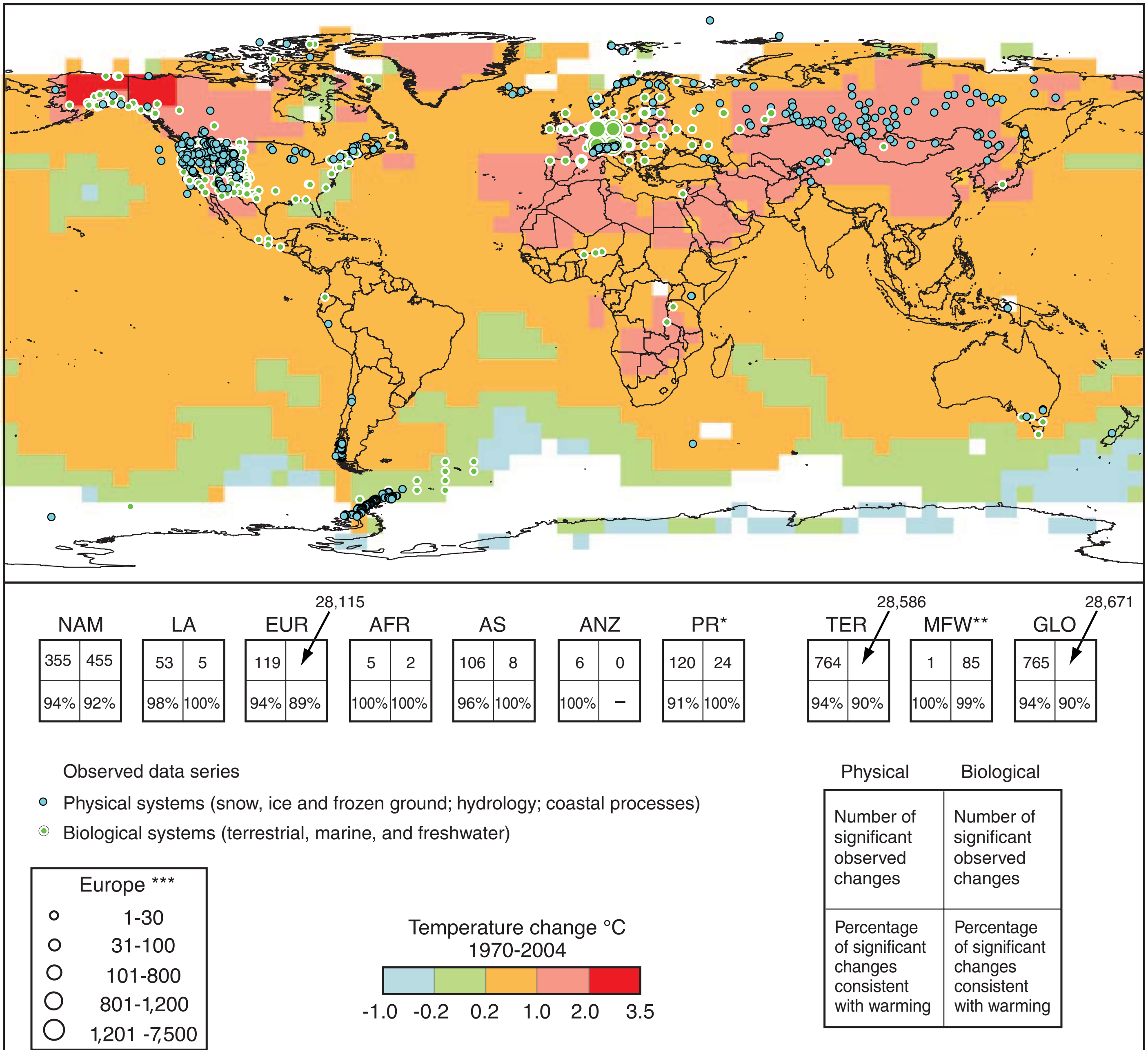
Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. ***{WGII SPM}***

There is *high confidence* that natural systems related to snow, ice and frozen ground (including permafrost) are affected. Examples are:

- enlargement and increased numbers of glacial lakes *{WGII 1.3, SPM}*
- increasing ground instability in permafrost regions and rock avalanches in mountain regions *{WGII 1.3, SPM}*
- changes in some Arctic and Antarctic ecosystems, including those in sea-ice biomes, and predators at high levels of the food web. *{WGII 1.3, 4.4, 15.4, SPM}*

Based on growing evidence, there is *high confidence* that the following effects on hydrological systems are occurring: increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers in many regions, with effects on thermal structure and water quality. *{WGII 1.3, 15.2, SPM}*

Changes in physical and biological systems and surface temperature 1970-2004



* Polar regions include also observed changes in marine and freshwater biological systems.

** Marine and freshwater includes observed changes at sites and large areas in oceans, small islands and continents. Locations of large-area marine changes are not shown on the map.

*** Circles in Europe represent 1 to 7,500 data series.

Figure 1.2. *Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which about 70 are new since the TAR) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 x 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, …, PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map. {WGII Figure SPM.1, Figure 1.8, Figure 1.9; WGI Figure 3.9b}*

There is *very high confidence*, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems**,** including such changes as earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying; and poleward and upward shifts in ranges in plant and animal species. Based on satellite observations since the early 1980s, there is *high confidence* that there has been a trend in many regions towards earlier 'greening' of vegetation in the spring linked to longer thermal growing seasons due to recent warming. *{WGII 1.3, 8.2, 14.2, SPM}*

There is *high confidence*, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. These include: shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range changes and earlier fish migrations in rivers. While there is increasing evidence of climate change impacts on coral reefs, separating the impacts of climate-related stresses from other stresses (e.g. overfishing and pollution) is difficult. *{WGII 1.3, SPM}*

Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. ***{WGII SPM}***

Effects of temperature increases have been documented with *medium confidence* in the following managed and human systems:

- agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbances of forests due to fires and pests *{WGII 1.3, SPM}*
- some aspects of human health, such as excess heat-related mortality in Europe, changes in infectious disease vectors in parts of Europe, and earlier onset of and increases in seasonal production of allergenic pollen in Northern Hemisphere high and mid-latitudes *{WGII 1.3, 8.2, 8.ES, SPM}*
- some human activities in the Arctic (e.g. hunting and shorter travel seasons over snow and ice) and in lower-elevation alpine areas (such as limitations in mountain sports). *{WGII 1.3, SPM}*

Sea level rise and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas. However, based on the published literature, the impacts have not yet become established trends. *{WGII 1.3, 1.ES, SPM}*

1.3 Consistency of changes in physical and biological systems with warming

Changes in the ocean and on land, including observed decreases in snow cover and Northern Hemisphere sea ice extent, thinner sea ice, shorter freezing seasons of lake and river ice, glacier melt, decreases in permafrost extent, increases in soil temperatures and borehole temperature profiles, and sea level rise, provide additional evidence that the world is warming. *{WGI 3.9}*

Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (Figure 1.2). *{WGII 1.4, SPM}*

1.4 Some aspects of climate have not been observed to change

Some aspects of climate appear not to have changed and, for some, data inadequacies mean that it cannot be determined if they have changed. Antarctic sea ice extent shows inter-annual variability and localised changes but no statistically significant average multi-decadal trend, consistent with the lack of rise in near-surface atmospheric temperatures averaged across the continent. There is insufficient evidence to determine whether trends exist in some other variables, for example the meridional overturning circulation (MOC) of the global ocean or small-scale phenomena such as tornadoes, hail, lightning and dust storms. There is no clear trend in the annual numbers of tropical cyclones. *{WGI 3.2, 3.8, 4.4, 5.3, SPM}*

2

Causes of change

Causes of change

This Topic considers both natural and anthropogenic drivers of climate change, including the chain from greenhouse gas (GHG) emissions to atmospheric concentrations to radiative forcing[4] to climate responses and effects.

2.1 Emissions of long-lived GHGs

The radiative forcing of the climate system is dominated by the long-lived GHGs, and this section considers those whose emissions are covered by the UNFCCC.

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (Figure 2.1).[5] ***{WGIII 1.3, SPM}***

Carbon dioxide (CO_2) is the most important anthropogenic GHG. Its annual emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004 (Figure 2.1). The rate of growth of CO_2-eq emissions was much higher during the recent 10-year period of 1995-2004 (0.92 GtCO_2-eq per year) than during the previous period of 1970-1994 (0.43 GtCO_2-eq per year). *{WGIII 1.3, TS.1, SPM}*

Carbon dioxide-equivalent (CO_2-eq) emissions and concentrations

GHGs differ in their warming influence (radiative forcing) on the global climate system due to their different radiative properties and lifetimes in the atmosphere. These warming influences may be expressed through a common metric based on the radiative forcing of CO_2.

- ***CO_2-equivalent emission*** is the amount of CO_2 emission that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of GHGs. The equivalent CO_2 emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon.[6] For a mix of GHGs it is obtained by summing the equivalent CO_2 emissions of each gas. Equivalent CO_2 emission is a standard and useful metric for comparing emissions of different GHGs but does not imply the same climate change responses (see WGI 2.10).
- ***CO_2-equivalent concentration*** is the concentration of CO_2 that would cause the same amount of radiative forcing as a given mixture of CO_2 and other forcing components.[7]

The largest growth in GHG emissions between 1970 and 2004 has come from energy supply, transport and industry, while residential and commercial buildings, forestry (including deforestation) and agriculture sectors have been growing at a lower rate. The

Global anthropogenic GHG emissions

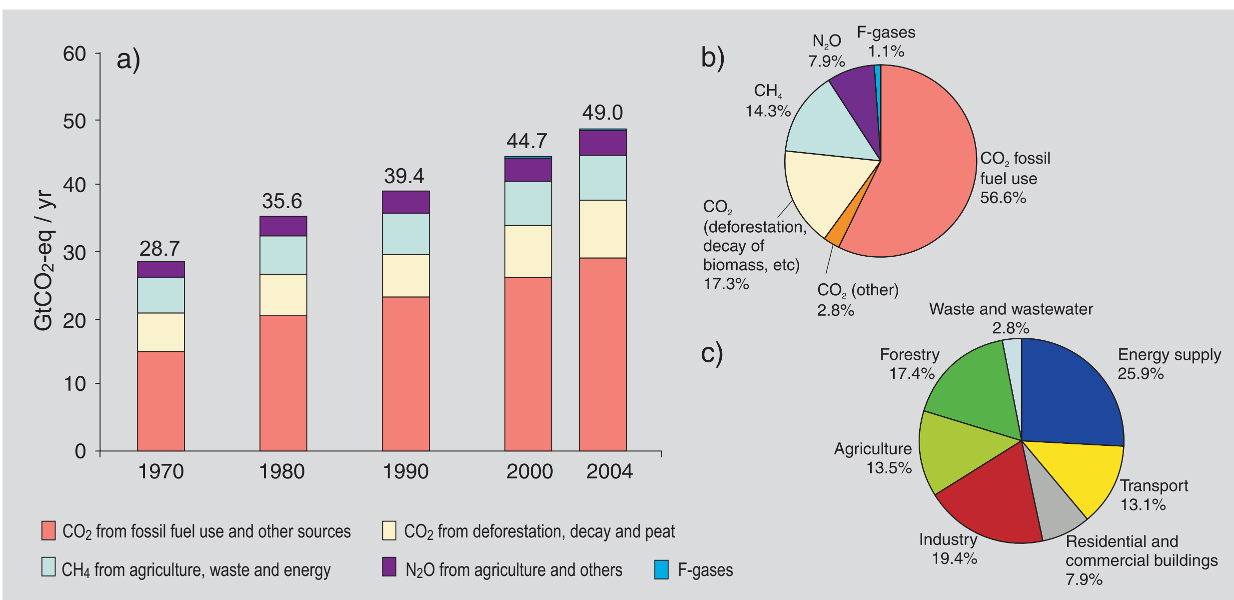


Figure 2.1. (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation.) {WGIII Figures TS.1a, TS.1b, TS.2b}

[4] *Radiative forcing* is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. In this report radiative forcing values are for changes relative to pre-industrial conditions defined at 1750 and are expressed in watts per square metre (W/m²).

[5] Includes only carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6), whose emissions are covered by the UNFCCC. These GHGs are weighted by their 100-year Global Warming Potentials (GWPs), using values consistent with reporting under the UNFCCC.

[6] This report uses 100-year GWPs and numerical values consistent with reporting under the UNFCCC.

[7] Such values may consider only GHGs, or a combination of GHGs and aerosols.

sectoral sources of GHGs in 2004 are considered in Figure 2.1c. *{WGIII 1.3, SPM}*

The effect on global emissions of the decrease in global energy intensity (-33%) during 1970 to 2004 has been smaller than the combined effect of global income growth (77%) and global population growth (69%); both drivers of increasing energy-related CO_2 emissions. The long-term trend of declining CO_2 emissions per unit of energy supplied reversed after 2000. *{WGIII 1.3, Figure SPM.2, SPM}*

Differences in per capita income, per capita emissions and energy intensity among countries remain significant. In 2004, UNFCCC Annex I countries held a 20% share in world population, produced 57% of the world's Gross Domestic Product based on Purchasing Power Parity (GDP_{ppp}) and accounted for 46% of global GHG emissions (Figure 2.2). *{WGIII 1.3, SPM}*

2.2 Drivers of climate change

Changes in the atmospheric concentrations of GHGs and aerosols, land cover and solar radiation alter the energy balance of the climate system and are drivers of climate change. They affect the absorption, scattering and emission of radiation within the atmosphere and at the Earth's surface. The resulting positive or negative changes in energy balance due to these factors are expressed as radiative forcing[4], which is used to compare warming or cooling influences on global climate. *{WGI TS.2}*

Human activities result in emissions of four long-lived GHGs: CO_2, methane (CH_4), nitrous oxide (N_2O) and halocarbons (a group of gases containing fluorine, chlorine or bromine). Atmospheric concentrations of GHGs increase when emissions are larger than removal processes.

Global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years (Figure 2.3). The atmospheric concentrations of CO_2 and CH_4 in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is *very likely* that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. The increase in N_2O concentration is primarily due to agriculture. ***{WGI 2.3, 7.3, SPM}***

The global atmospheric concentration of CO_2 increased from a pre-industrial value of about 280ppm to 379ppm in 2005. The annual CO_2 concentration growth rate was larger during the last 10 years (1995-2005 average: 1.9ppm per year) than it has been since the beginning of continuous direct atmospheric measurements (1960-2005 average: 1.4ppm per year), although there is year-to-year variability in growth rates. *{WGI 2.3, 7.3, SPM; WGIII 1.3}*

The global atmospheric concentration of CH_4 has increased from a pre-industrial value of about 715ppb to 1732ppb in the early 1990s, and was 1774ppb in 2005. Growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. *{WGI 2.3, 7.4, SPM}*

The global atmospheric N_2O concentration increased from a pre-industrial value of about 270ppb to 319ppb in 2005. *{WGI 2.3, 7.4, SPM}*

Many halocarbons (including hydrofluorocarbons) have increased from a near-zero pre-industrial background concentration, primarily due to human activities. *{WGI 2.3, SPM; SROC SPM}*

There is *very high confidence* that the global average net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W/m² (Figure 2.4). ***{WGI 2.3, 6.5, 2.9, SPM}***

The combined radiative forcing due to increases in CO_2, CH_4 and N_2O is +2.3 [+2.1 to +2.5] W/m², and its rate of increase during

Regional distribution of GHG emissions by population and by GDP_{PPP}

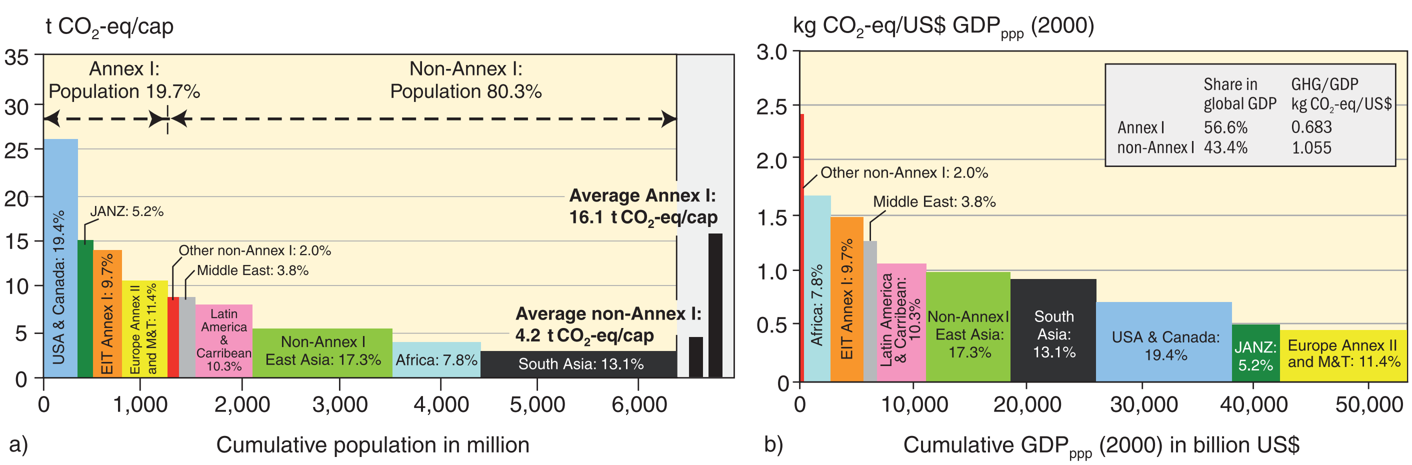


Figure 2.2. (a) Distribution of regional per capita GHG emissions according to the population of different country groupings in 2004 (see appendix for definitions of country groupings). (b) Distribution of regional GHG emissions per US\$ of GDP_{PPP} over the GDP of different country groupings in 2004. The percentages in the bars in both panels indicate a region's share in global GHG emissions. {WGIII Figures SPM.3a, SPM.3b}

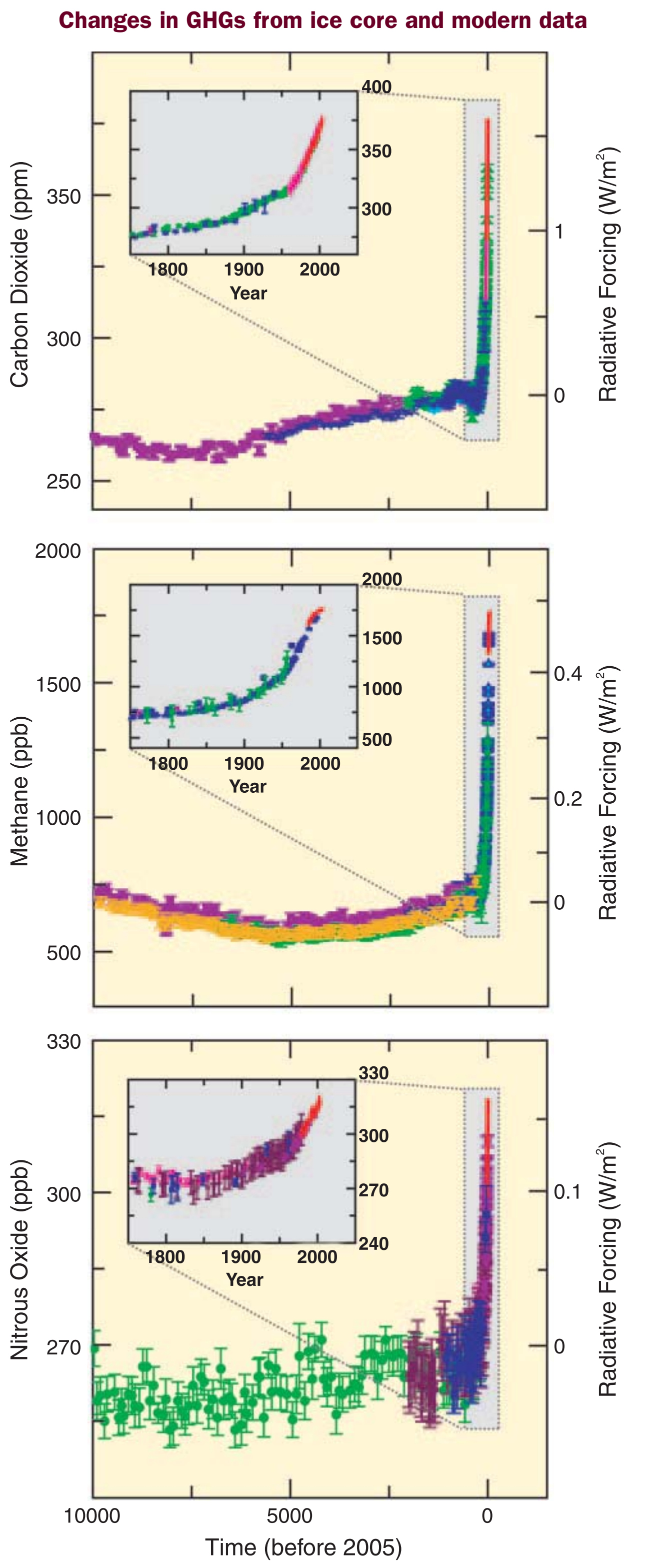


Figure 2.3. *Atmospheric concentrations of CO_2, CH_4 and N_2O over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings relative to 1750 are shown on the right hand axes of the large panels. {WGI Figure SPM.1}*

the industrial era is *very likely* to have been unprecedented in more than 10,000 years (Figures 2.3 and 2.4). The CO_2 radiative forcing increased by 20% from 1995 to 2005, the largest change for any decade in at least the last 200 years. *{WGI 2.3, 6.4, SPM}*

Anthropogenic contributions to aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect, with a total direct radiative forcing of -0.5 [-0.9 to -0.1] W/m² and an indirect cloud albedo forcing of -0.7 [-1.8 to -0.3] W/m². Aerosols also influence precipitation. *{WGI 2.4, 2.9, 7.5, SPM}*

In comparison, changes in solar irradiance since 1750 are estimated to have caused a small radiative forcing of +0.12 [+0.06 to +0.30] W/m², which is less than half the estimate given in the TAR. *{WGI 2.7, SPM}*

2.3 Climate sensitivity and feedbacks

The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is defined as the equilibrium global average surface warming following a doubling of CO_2 concentration. Progress since the TAR enables an assessment that climate sensitivity is *likely* to be in the range of 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values. *{WGI 8.6, 9.6, Box 10.2, SPM}*

Feedbacks can amplify or dampen the response to a given forcing. Direct emission of water vapour (a greenhouse gas) by human activities makes a negligible contribution to radiative forcing. However, as global average temperature increases, tropospheric water vapour concentrations increase and this represents a key positive feedback but not a forcing of climate change. Water vapour changes represent the largest feedback affecting equilibrium climate sensitivity and are now better understood than in the TAR. Cloud feedbacks remain the largest source of uncertainty. Spatial patterns of climate response are largely controlled by climate processes and feedbacks. For example, sea-ice albedo feedbacks tend to enhance the high latitude response. *{WGI 2.8, 8.6, 9.2, TS.2.1.3, TS.2.5, SPM}*

Warming reduces terrestrial and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. This positive carbon cycle feedback leads to larger atmospheric CO_2 increases and greater climate change for a given emissions scenario, but the strength of this feedback effect varies markedly among models. *{WGI 7.3, TS.5.4, SPM; WGII 4.4}*

2.4 Attribution of climate change

Attribution evaluates whether observed changes are quantitatively consistent with the expected response to external forcings (e.g. changes in solar irradiance or anthropogenic GHGs) and inconsistent with alternative physically plausible explanations. *{WGI TS.4, SPM}*

Radiative forcing components

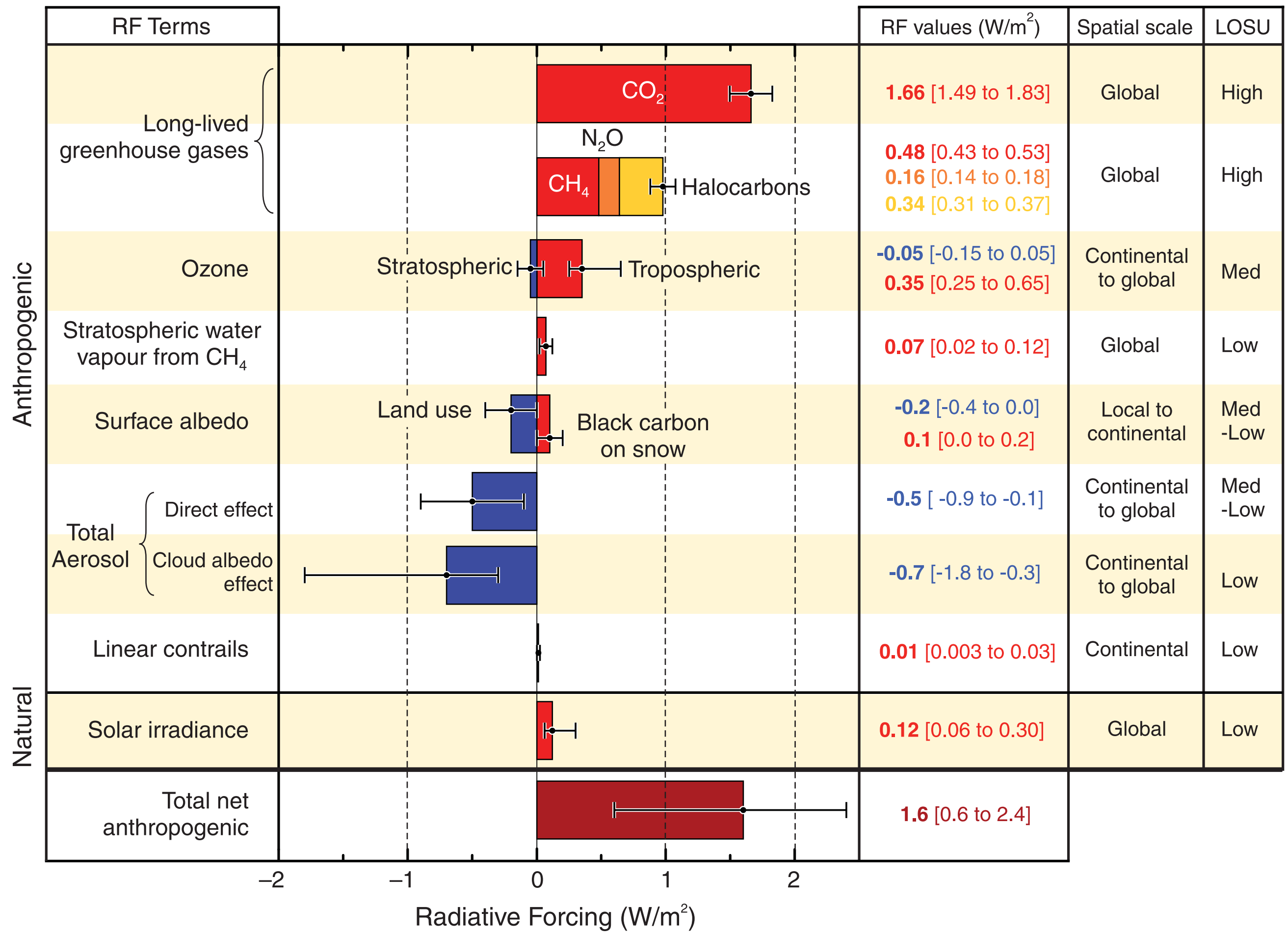


Figure 2.4. *Global average radiative forcing (RF) in 2005 (best estimates and 5 to 95% uncertainty ranges) with respect to 1750 for CO_2, CH_4, N_2O and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). Aerosols from explosive volcanic eruptions contribute an additional episodic cooling term for a few years following an eruption. The range for linear contrails does not include other possible effects of aviation on cloudiness. {WGI Figure SPM.2}*

Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations.[8] This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in GHG concentrations" (Figure 2.5). ***{WGI 9.4, SPM}***

The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is *extremely unlikely* that global climate change of the past 50 years can be explained without external forcing and *very likely* that it is not due to known natural causes alone. During this period, the sum of solar and volcanic forcings would *likely* have produced cooling, not warming. Warming of the climate system has been detected in changes in surface and atmospheric temperatures and in temperatures of the upper several hundred metres of the ocean. The observed pattern of tropospheric warming and stratospheric cooling is *very likely* due to the combined influences of GHG increases and stratospheric ozone depletion. It is *likely* that increases in GHG concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place. *{WGI 2.9, 3.2, 3.4, 4.8, 5.2, 7.5, 9.4, 9.5, 9.7, TS.4.1, SPM}*

It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica) (Figure 2.5). ***{WGI 3.2, 9.4, SPM}***

The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are simulated only by models that include anthropogenic forcing. No coupled global climate model that has used natural forcing only has reproduced the continental mean warming trends in individual continents (except Antarctica) over the second half of the 20th century. *{WGI 3.2, 9.4, TS.4.2, SPM}*

[8] Consideration of remaining uncertainty is based on current methodologies.

Global and continental temperature change

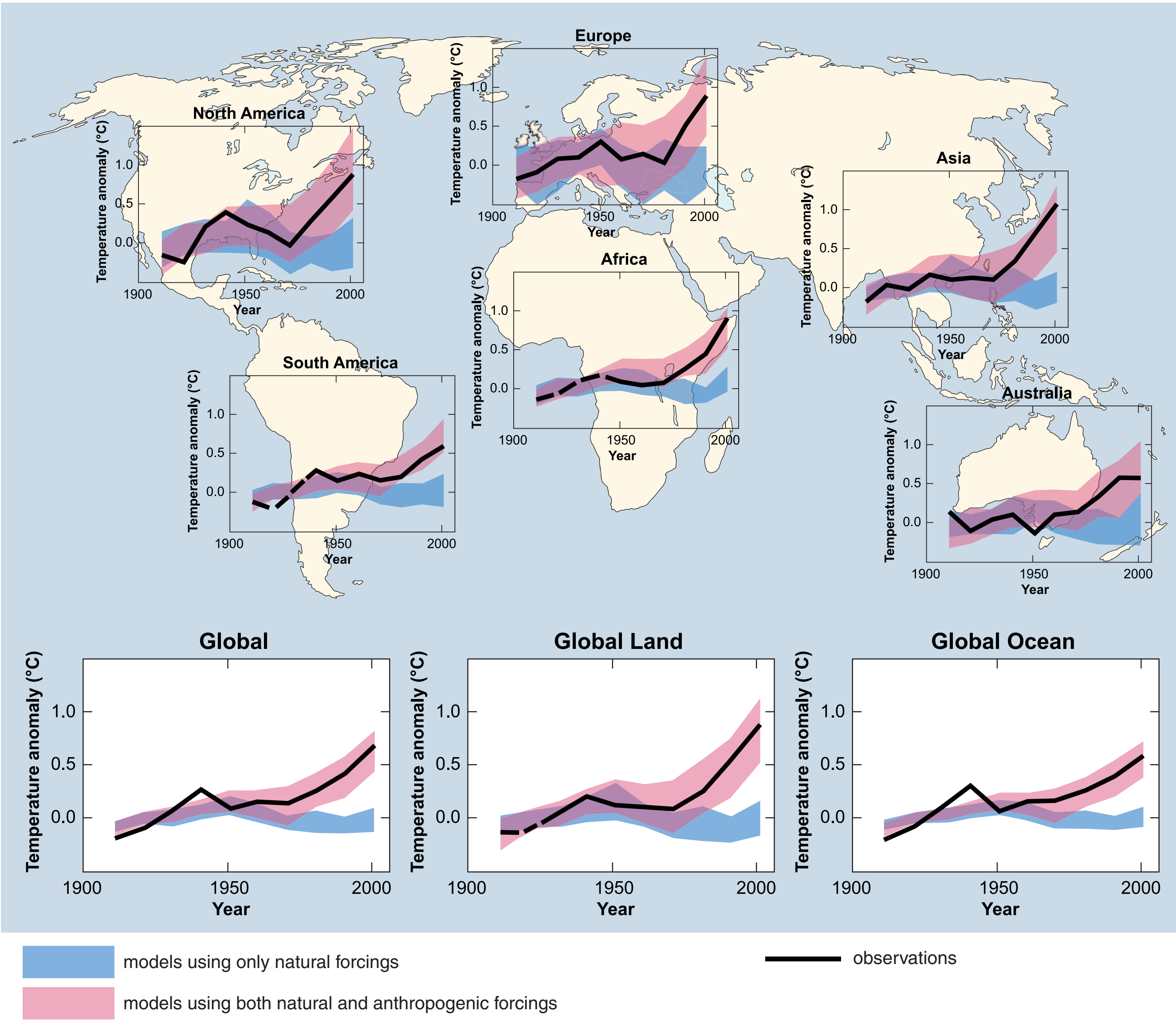


Figure 2.5. *Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. {WGI Figure SPM.4}*

Difficulties remain in simulating and attributing observed temperature changes at smaller scales. On these scales, natural climate variability is relatively larger, making it harder to distinguish changes expected due to external forcings. Uncertainties in local forcings, such as those due to aerosols and land-use change, and feedbacks also make it difficult to estimate the contribution of GHG increases to observed small-scale temperature changes. *{WGI 8.3, 9.4, SPM}*

Advances since the TAR show that discernible human influences extend beyond average temperature to other aspects of climate, including temperature extremes and wind patterns. ***{WGI 9.4, 9.5, SPM}***

Temperatures of the most extreme hot nights, cold nights and cold days are *likely* to have increased due to anthropogenic forcing. It is *more likely than not* that anthropogenic forcing has increased the risk of heat waves. Anthropogenic forcing is *likely* to have contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns in both hemispheres. However, the observed changes in the Northern Hemisphere circulation are larger than simulated by models in response to 20th century forcing change. *{WGI 3.5, 3.6, 9.4, 9.5, 10.3, SPM}*

It is *very likely* that the response to anthropogenic forcing contributed to sea level rise during the latter half of the 20th century. There is some evidence of the impact of human climatic influence

on the hydrological cycle, including the observed large-scale patterns of changes in land precipitation over the 20th century. It is *more likely than not* that human influence has contributed to a global trend towards increases in area affected by drought since the 1970s and the frequency of heavy precipitation events. *{WGI 3.3, 5.5, 9.5, TS.4.1, TS.4.3}*

Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems. ***{WGII 1.4}***

A synthesis of studies strongly demonstrates that the spatial agreement between regions of significant warming across the globe and the locations of significant observed changes in many natural systems consistent with warming is *very unlikely* to be due solely to natural variability of temperatures or natural variability of the systems. Several modelling studies have linked some specific responses in physical and biological systems to anthropogenic warming, but only a few such studies have been performed. Taken together with evidence of significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica), it is *likely* that anthropogenic warming over the last three decades has had a discernible influence on many natural systems. *{WGI 3.2, 9.4, SPM; WGII 1.4, SPM}*

Limitations and gaps currently prevent more complete attribution of the causes of observed natural system responses to anthropogenic warming. The available analyses are limited in the number of systems, length of records and locations considered. Natural temperature variability is larger at the regional than the global scale, thus affecting identification of changes to external forcing. At the regional scale, other non-climate factors (such as land-use change, pollution and invasive species) are influential. *{WGII 1.2, 1.3, 1.4, SPM}*

3

Climate change and its impacts in the near and long term under different scenarios

3.1 Emissions scenarios

There is *high agreement* and *much evidence*[9] that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. Baseline emissions scenarios published since the IPCC Special Report on Emissions Scenarios (SRES, 2000) are comparable in range to those presented in SRES (see Box on SRES scenarios and Figure 3.1).[10] *{WGIII 1.3, 3.2, SPM}*

The SRES scenarios project an increase of baseline global GHG emissions by a range of 9.7 to 36.7 $GtCO_2$-eq (25 to 90%) between 2000 and 2030. In these scenarios, fossil fuels are projected to maintain their dominant position in the global energy mix to 2030 and beyond. Hence CO_2 emissions from energy use between 2000 and 2030 are projected to grow 40 to 110% over that period. *{WGIII 1.3, SPM}*

Studies published since SRES (i.e. post-SRES scenarios) have used lower values for some drivers for emissions, notably population projections. However, for those studies incorporating these new population projections, changes in other drivers, such as economic growth, result in little change in overall emission levels. Economic growth projections for Africa, Latin America and the Middle East to 2030 in post-SRES baseline scenarios are lower than in SRES, but this has only minor effects on global economic growth and overall emissions. *{WGIII 3.2, TS.3, SPM}*

Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. *{WGIII 3.2, TS.3, SPM}*

Available studies indicate that the choice of exchange rate for Gross Domestic Product (GDP) (Market Exchange Rate, MER or Purchasing Power Parity, PPP) does not appreciably affect the projected emissions, when used consistently.[11] The differences, if any, are small compared to the uncertainties caused by assumptions on other parameters in the scenarios, e.g. technological change. *{WGIII 3.2, TS.3, SPM}*

Scenarios for GHG emissions from 2000 to 2100 in the absence of additional climate policies

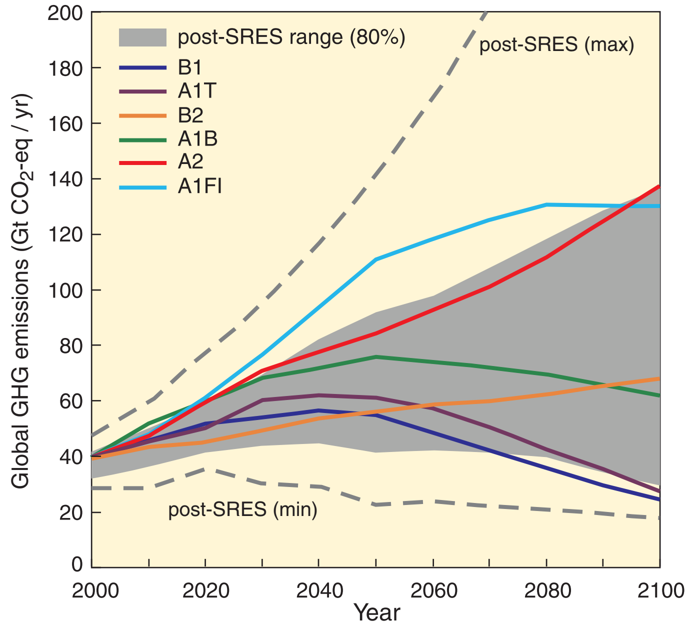


Figure 3.1. *Global GHG emissions (in $GtCO_2$-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O and F-gases. {WGIII 1.3, 3.2, Figure SPM.4}*

SRES scenarios

SRES refers to the scenarios described in the IPCC Special Report on Emissions Scenarios (SRES, 2000). The SRES scenarios are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. The SRES scenarios do not include additional climate policies above current ones. The emissions projections are widely used in the assessments of future climate change, and their underlying assumptions with respect to socio-economic, demographic and technological change serve as inputs to many recent climate change vulnerability and impact assessments. *{WGI 10.1; WGII 2.4; WGIII TS.1, SPM}*

The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change. No likelihood has been attached to any of the SRES scenarios. *{WGIII TS.1, SPM}*

[9] Agreement/evidence statements in italics represent calibrated expressions of uncertainty and confidence. See Box 'Treatment of uncertainty' in the Introduction for an explanation of these terms.

[10] Baseline scenarios do not include additional climate policies above current ones; more recent studies differ with respect to UNFCCC and Kyoto Protocol inclusion. Emission pathways of mitigation scenarios are discussed in Topic 5.

[11] Since the TAR, there has been a debate on the use of different exchange rates in emissions scenarios. Two metrics are used to compare GDP between countries. Use of MER is preferable for analyses involving internationally traded products. Use of PPP is preferable for analyses involving comparisons of income between countries at very different stages of development. Most of the monetary units in this report are expressed in MER. This reflects the large majority of emissions mitigation literature that is calibrated in MER. When monetary units are expressed in PPP, this is denoted by GDP_{PPP}. {WGIII SPM}

3.2 Projections of future changes in climate

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards, temperature projections increasingly depend on specific emissions scenarios (Figure 3.2). ***{WGI 10.3, 10.7; WGIII 3.2}***

Since the IPCC's first report in 1990, assessed projections have suggested global averaged temperature increases between about 0.15 and 0.3°C per decade from 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections. *{WGI 1.2, 3.2}*

3.2.1 21st century global changes

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. ***{WGI 10.3}***

Advances in climate change modelling now enable best estimates and *likely* assessed uncertainty ranges to be given for projected warming for different emissions scenarios. Table 3.1 shows best estimates and *likely* ranges for global average surface air warming for the six SRES marker emissions scenarios (including climate-carbon cycle feedbacks). *{WGI 10.5}*

Although these projections are broadly consistent with the span quoted in the TAR (1.4 to 5.8°C), they are not directly comparable. Assessed upper ranges for temperature projections are larger than in the TAR mainly because the broader range of models now available suggests stronger climate-carbon cycle feedbacks. For the A2 scenario, for example, the climate-carbon cycle feedback increases the corresponding global average warming at 2100 by more than 1°C. Carbon feedbacks are discussed in Topic 2.3. *{WGI 7.3, 10.5, SPM}*

Because understanding of some important effects driving sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise. Model-based projections of global average sea level rise at the end of the 21st century (2090-2099) are shown in Table 3.1. For each scenario, the mid-point of the range in Table 3.1 is within 10% of the TAR model average for 2090-2099. The ranges are narrower than in the TAR mainly because of improved information about some uncertainties in the projected contributions.[12] The sea level projections do not include uncertainties in climate-carbon cycle feedbacks nor do they include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. Therefore the upper values of the ranges given are not to be considered upper bounds for sea level rise. The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. If this contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios shown in Table 3.1 would increase by 0.1 to 0.2m.[13] *{WGI 10.6, SPM}*

Table 3.1. *Projected global average surface warming and sea level rise at the end of the 21st century. {WGI 10.5, 10.6, Table 10.7, Table SPM.3}*

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) [a, d]		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations[b]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:
a) These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity, and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs) as well as observational constraints.
b) Year 2000 constant composition is derived from AOGCMs only.
c) All scenarios above are six SRES marker scenarios. Approximate CO_2-eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the WGI TAR) for the SRES B1, AIT, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550ppm, respectively.
d) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

[12] TAR projections were made for 2100, whereas the projections for this report are for 2090-2099. The TAR would have had similar ranges to those in Table 3.1 if it had treated uncertainties in the same way.

[13] For discussion of the longer term see Sections 3.2.3 and 5.2.

3.2.2 21st century regional changes

There is now higher confidence than in the TAR in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation and some aspects of extremes and sea ice. ***{WGI 8.2, 8.3, 8.4, 8.5, 9.4, 9.5, 10.3, 11.1}***

Projected warming in the 21st century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and northern North Atlantic, continuing recent observed trends (Figure 3.2 right panels). *{WGI 10.3, SPM}*

Snow cover area is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century. *{WGI 10.3, 10.6, SPM; WGII 15.3.4}*

It is *very likely* that hot extremes, heat waves and heavy precipitation events will become more frequent. *{SYR Table 3.2; WGI 10.3, SPM}*

Based on a range of models, it is *likely* that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea-surface temperatures. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period. *{WGI 3.8, 9.5, 10.3, SPM}*

Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation and temperature patterns, continuing the broad pattern of observed trends over the last half-century. *{WGI 3.6, 10.3, SPM}*

Since the TAR there is an improving understanding of projected patterns of precipitation. Increases in the amount of precipitation are *very likely* in high-latitudes, while decreases are *likely* in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100, Figure 3.3), continuing observed patterns in recent trends. *{WGI 3.3, 8.3, 9.5, 10.3, 11.2-11.9, SPM}*

3.2.3 Changes beyond the 21st century

Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilised. ***{WGI 10.4, 10.5, 10.7, SPM}***

If radiative forcing were to be stabilised, keeping all the radiative forcing agents constant at B1 or A1B levels in 2100, model experiments show that a further increase in global average temperature of about 0.5°C would still be expected by 2200. In addition, thermal expansion alone would lead to 0.3 to 0.8m of sea level rise by 2300 (relative to 1980-1999). Thermal expansion would continue for many centuries, due to the time required to transport heat into the deep ocean. *{WGI 10.7, SPM}*

Atmosphere-Ocean General Circulation Model projections of surface warming

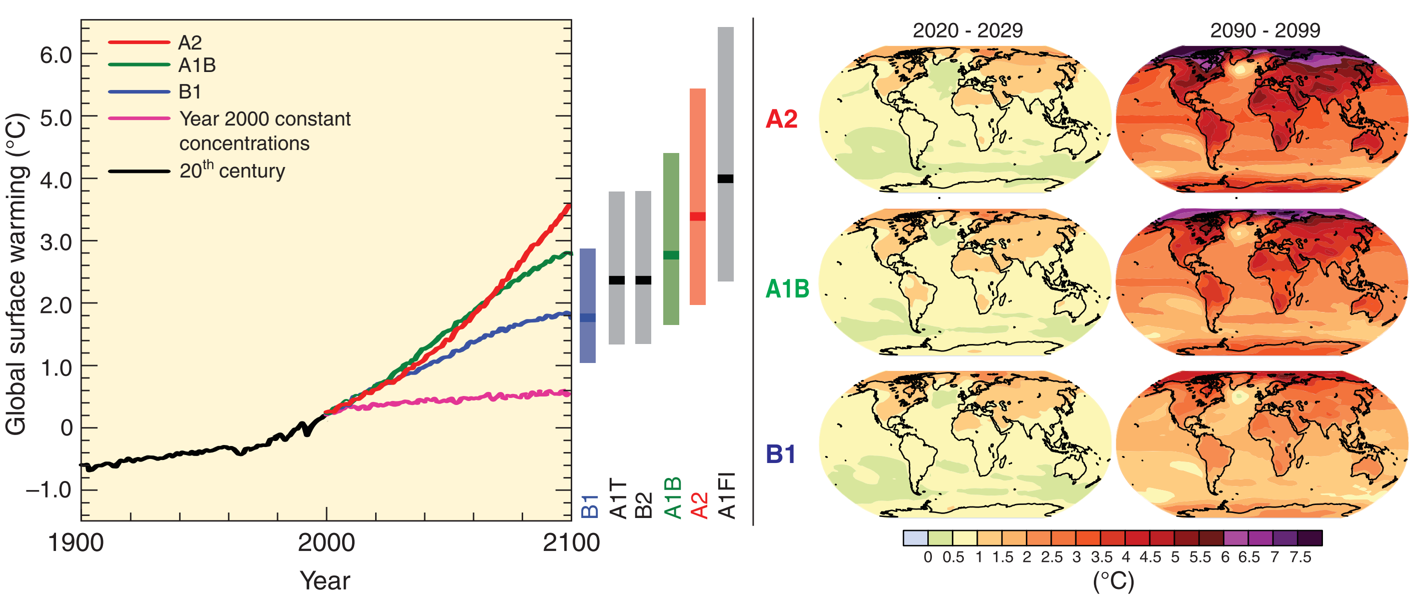


Figure 3.2. ***Left panel:*** *Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the* likely *range assessed for the six SRES marker scenarios at 2090-2099 relative to 1980-1999. The assessment of the best estimate and* likely *ranges in the bars includes the Atmosphere-Ocean General Circulation Models (AOGCMs) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints.* ***Right panels:*** *Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom) SRES scenarios averaged over decades 2020-2029 (left) and 2090-2099 (right). {WGI 10.4, 10.8, Figures 10.28, 10.29, SPM}*

Multi-model projected patterns of precipitation changes

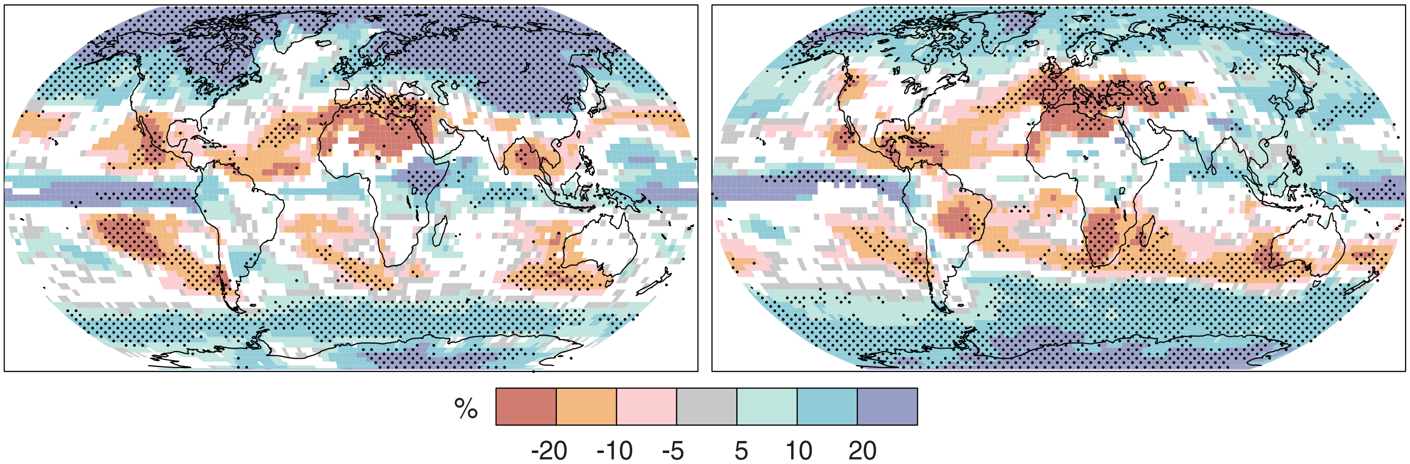


Figure 3.3. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {WGI Figure 10.9, SPM}

Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest ice mass losses increase with temperature more rapidly than gains due to increased precipitation and that the surface mass balance becomes negative (net ice loss) at a global average warming (relative to pre-industrial values) in excess of 1.9 to 4.6°C. If such a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7m. The corresponding future temperatures in Greenland (1.9 to 4.6°C global) are comparable to those inferred for the last interglacial period 125,000 years ago, when palaeoclimatic information suggests reductions of polar land ice extent and 4 to 6m of sea level rise. *{WGI 6.4, 10.7, SPM}*

Dynamical processes related to ice flow – which are not included in current models but suggested by recent observations – could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude. *{WGI 4.6, 10.7, SPM}*

Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. *{WGI 10.7, SPM}*

Both past and future anthropogenic CO_2 emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the time scales required for the removal of this gas from the atmosphere. *{WGI 7.3, 10.3, Figure 7.12, Figure 10.35, SPM}*

Estimated long-term (multi-century) warming corresponding to the six AR4 WG III stabilisation categories is shown in Figure 3.4.

Estimated multi-century warming relative to 1980-1999 for AR4 stabilisation categories

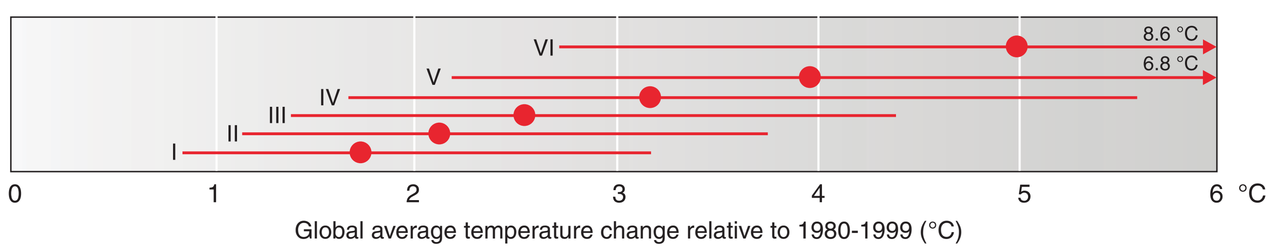


Figure 3.4. Estimated long-term (multi-century) warming corresponding to the six AR4 WG III stabilisation categories (Table 5.1). The temperature scale has been shifted by -0.5°C compared to Table 5.1 to account approximately for the warming between pre-industrial and 1980-1999. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For GHG emissions scenarios that lead to stabilisation at levels comparable to SRES B1 and A1B by 2100 (600 and 850 ppm CO_2-eq; category IV and V), assessed models project that about 65 to 70% of the estimated global equilibrium temperature increase, assuming a climate sensitivity of 3°C, would be realised at the time of stabilisation. For the much lower stabilisation scenarios (category I and II, Figure 5.1), the equilibrium temperature may be reached earlier. {WGI 10.7.2}

3.3 Impacts of future climate changes

More specific information is now available across a wide range of systems and sectors concerning the nature of future impacts, including some fields not covered in previous assessments. *{WGII TS.4, SPM}*

The following is a selection of key findings[14] regarding the impacts of climate change on systems, sectors and regions, as well as some findings on vulnerability[15], for the range of climate changes projected over the 21st century. Unless otherwise stated, the confidence level in the projections is *high*. Global average temperature increases are given relative to 1980-1999. Additional information on impacts can be found in the WG II report. *{WGII SPM}*

3.3.1 Impacts on systems and sectors

Ecosystems

- The resilience of many ecosystems is *likely* to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (e.g. land-use change, pollution, fragmentation of natural systems, over-exploitation of resources). *{WGII 4.1-4.6, SPM}*
- Over the course of this century, net carbon uptake by terrestrial ecosystems is *likely* to peak before mid-century and then weaken or even reverse[16], thus amplifying climate change. *{WGII 4.ES, Figure 4.2, SPM}*
- Approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C (*medium confidence*). *{WGII 4.ES, Figure 4.2, SPM}*
- For increases in global average temperature exceeding 1.5 to 2.5°C and in concomitant atmospheric CO_2 concentrations, there are projected to be major changes in ecosystem structure and function, species' ecological interactions and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services, e.g. water and food supply. *{WGII 4.4, Box TS.6, SPM}*

Food

- Crop productivity is projected to increase slightly at mid- to high latitudes for local mean temperature increases of up to 1 to 3°C depending on the crop, and then decrease beyond that in some regions (*medium confidence*). *{WGII 5.4, SPM}*
- At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger (*medium confidence*). *{WGII 5.4, SPM}*
- Globally, the potential for food production is projected to increase with increases in local average temperature over a range of 1 to 3°C, but above this it is projected to decrease (*medium confidence*). *{WGII 5.4, 5.5, SPM}*

Coasts

- Coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea level rise. The effect will be exacerbated by increasing human-induced pressures on coastal areas (*very high confidence*). *{WGII 6.3, 6.4, SPM}*
- By the 2080s, many millions more people than today are projected to experience floods every year due to sea level rise. The numbers affected will be largest in the densely populated and low-lying megadeltas of Asia and Africa while small islands are especially vulnerable (*very high confidence*). *{WGII 6.4, 6.5, Table 6.11, SPM}*

Industry, settlements and society

- The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources and those in areas prone to extreme weather events, especially where rapid urbanisation is occurring. *{WGII 7.1, 7.3, 7.4, 7.5, SPM}*
- Poor communities can be especially vulnerable, in particular those concentrated in high-risk areas. *{WGII 7.2, 7.4, 5.4, SPM}*

Health

- The health status of millions of people is projected to be affected through, for example, increases in malnutrition; increased deaths, diseases and injury due to extreme weather events; increased burden of diarrhoeal diseases; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change; and the altered spatial distribution of some infectious diseases. *{WGI 7.4, Box 7.4; WGII 8.ES, 8.2, 8.4, SPM}*
- Climate change is projected to bring some benefits in temperate areas, such as fewer deaths from cold exposure, and some mixed effects such as changes in range and transmission potential of malaria in Africa. Overall it is expected that benefits will be outweighed by the negative health effects of rising temperatures, especially in developing countries. *{WGII 8.4, 8.7, 8ES, SPM}*
- Critically important will be factors that directly shape the health of populations such as education, health care, public health initiatives, and infrastructure and economic development. *{WGII 8.3, SPM}*

Water

- Water impacts are key for all sectors and regions. These are discussed below in the Box 'Climate change and water'.

[14] Criteria of choice: magnitude and timing of impact, confidence in the assessment, representative coverage of the system, sector and region.

[15] Vulnerability to climate change is the degree to which systems are susceptible to, and unable to cope with, adverse impacts.

[16] Assuming continued GHG emissions at or above current rates and other global changes including land-use changes.

Climate change and water

Climate change is expected to exacerbate current stresses on water resources from population growth and economic and land-use change, including urbanisation. On a regional scale, mountain snow pack, glaciers and small ice caps play a crucial role in freshwater availability. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st century, reducing water availability, hydropower potential, and changing seasonality of flows in regions supplied by meltwater from major mountain ranges (e.g. Hindu-Kush, Himalaya, Andes), where more than one-sixth of the world population currently lives. *{WGI 4.1, 4.5; WGII 3.3, 3.4, 3.5}*

Changes in precipitation (Figure 3.3) and temperature (Figure 3.2) lead to changes in runoff (Figure 3.5) and water availability. Runoff is projected with *high confidence* to increase by 10 to 40% by mid-century at higher latitudes and in some wet tropical areas, including populous areas in East and South-East Asia, and decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics, due to decreases in rainfall and higher rates of evapotranspiration. There is also *high confidence* that many semi-arid areas (e.g. the Mediterranean Basin, western United States, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change. Drought-affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, e.g. agriculture, water supply, energy production and health. Regionally, large increases in irrigation water demand as a result of climate changes are projected. *{WGI 10.3, 11.2-11.9; WGII 3.4, 3.5, Figure 3.5, TS.4.1, Box TS.5, SPM}*

The negative impacts of climate change on freshwater systems outweigh its benefits (*high confidence*). Areas in which runoff is projected to decline face a reduction in the value of the services provided by water resources (*very high confidence*). The beneficial impacts of increased annual runoff in some areas are *likely* to be tempered by negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality and flood risk. *{WGII 3.4, 3.5, TS.4.1}*

Available research suggests a significant future increase in heavy rainfall events in many regions, including some in which the mean rainfall is projected to decrease. The resulting increased flood risk poses challenges to society, physical infrastructure and water quality. It is *likely* that up to 20% of the world population will live in areas where river flood potential could increase by the 2080s. Increases in the frequency and severity of floods and droughts are projected to adversely affect sustainable development. Increased temperatures will further affect the physical, chemical and biological properties of freshwater lakes and rivers, with predominantly adverse impacts on many individual freshwater species, community composition and water quality. In coastal areas, sea level rise will exacerbate water resource constraints due to increased salinisation of groundwater supplies. *{WGI 11.2-11.9; WGII 3.2, 3.3, 3.4, 4.4}*

Projections and model consistency of relative changes in runoff by the end of the 21st century

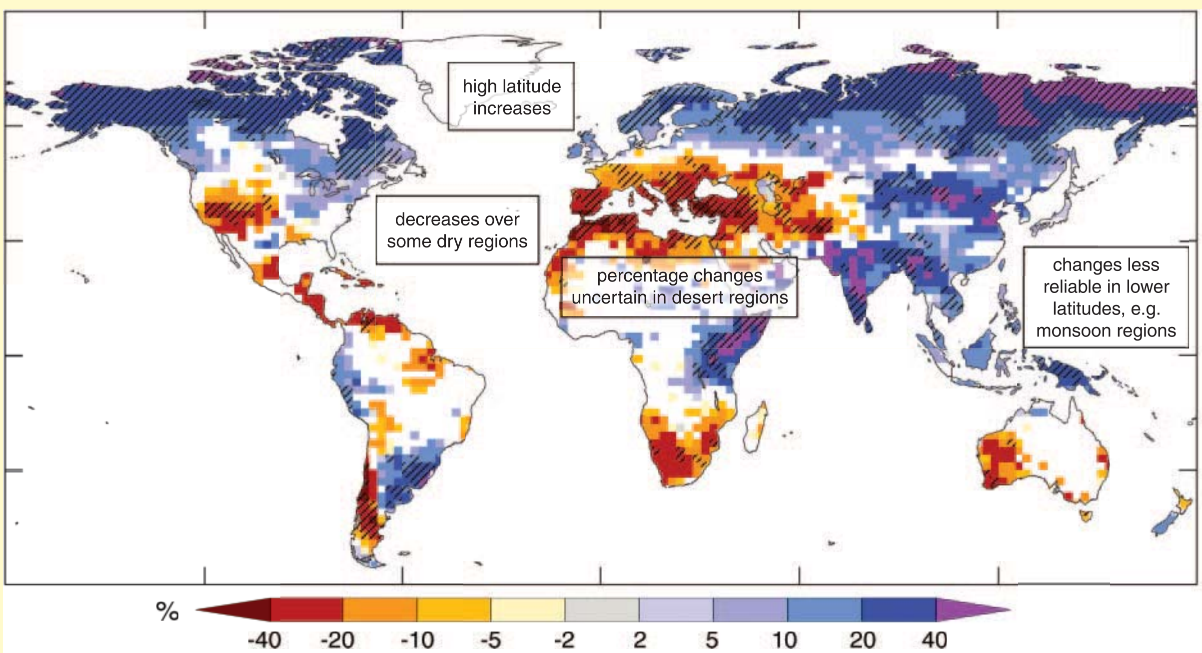


Figure 3.5. *Large-scale relative changes in annual runoff (water availability, in percent) for the period 2090-2099, relative to 1980-1999. Values represent the median of 12 climate models using the SRES A1B scenario. White areas are where less than 66% of the 12 models agree on the sign of change and hatched areas are where more than 90% of models agree on the sign of change. The quality of the simulation of the observed large-scale 20th century runoff is used as a basis for selecting the 12 models from the multi-model ensemble. The global map of annual runoff illustrates a large scale and is not intended to refer to smaller temporal and spatial scales. In areas where rainfall and runoff is very low (e.g. desert areas), small changes in runoff can lead to large percentage changes. In some regions, the sign of projected changes in runoff differs from recently observed trends. In some areas with projected increases in runoff, different seasonal effects are expected, such as increased wet season runoff and decreased dry season runoff. Studies using results from few climate models can be considerably different from the results presented here. {WGII Figure 3.4, adjusted to match the assumptions of Figure SYR 3.3; WGII 3.3.1, 3.4.1, 3.5.1}*

Studies since the TAR have enabled more systematic understanding of the timing and magnitude of impacts related to differing amounts and rates of climate change. *{WGII SPM}*

Examples of this new information for systems and sectors are presented in Figure 3.6. The upper panel shows impacts increasing with increasing temperature change. Their estimated magnitude and timing is also affected by development pathways (lower panel). *{WGII SPM}*

Depending on circumstances, some of the impacts shown in Figure 3.6 could be associated with 'key vulnerabilities', based on a number of criteria in the literature (magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts) (see Topic 5.2). *{WGII SPM}*

3.3.2 Impacts on regions[17]

Africa

- By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change. *{WGII 9.4, SPM}*
- By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition. *{WGII 9.4, SPM}*
- Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10% of GDP. *{WGII 9.4, SPM}*
- By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (*high confidence*). *{WGII Box TS.6, 9.4.4}*

Asia

- By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease. *{WGII 10.4, SPM}*
- Coastal areas, especially heavily populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers. *{WGII 10.4, SPM}*
- Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanisation, industrialisation and economic development. *{WGII 10.4, SPM}*
- Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle. *{WGII 10.4, SPM}*

Australia and New Zealand

- By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. *{WGII 11.4, SPM}*
- By 2030, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions. *{WGII 11.4, SPM}*
- By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions. *{WGII 11.4, SPM}*
- By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding. *{WGII 11.4, SPM}*

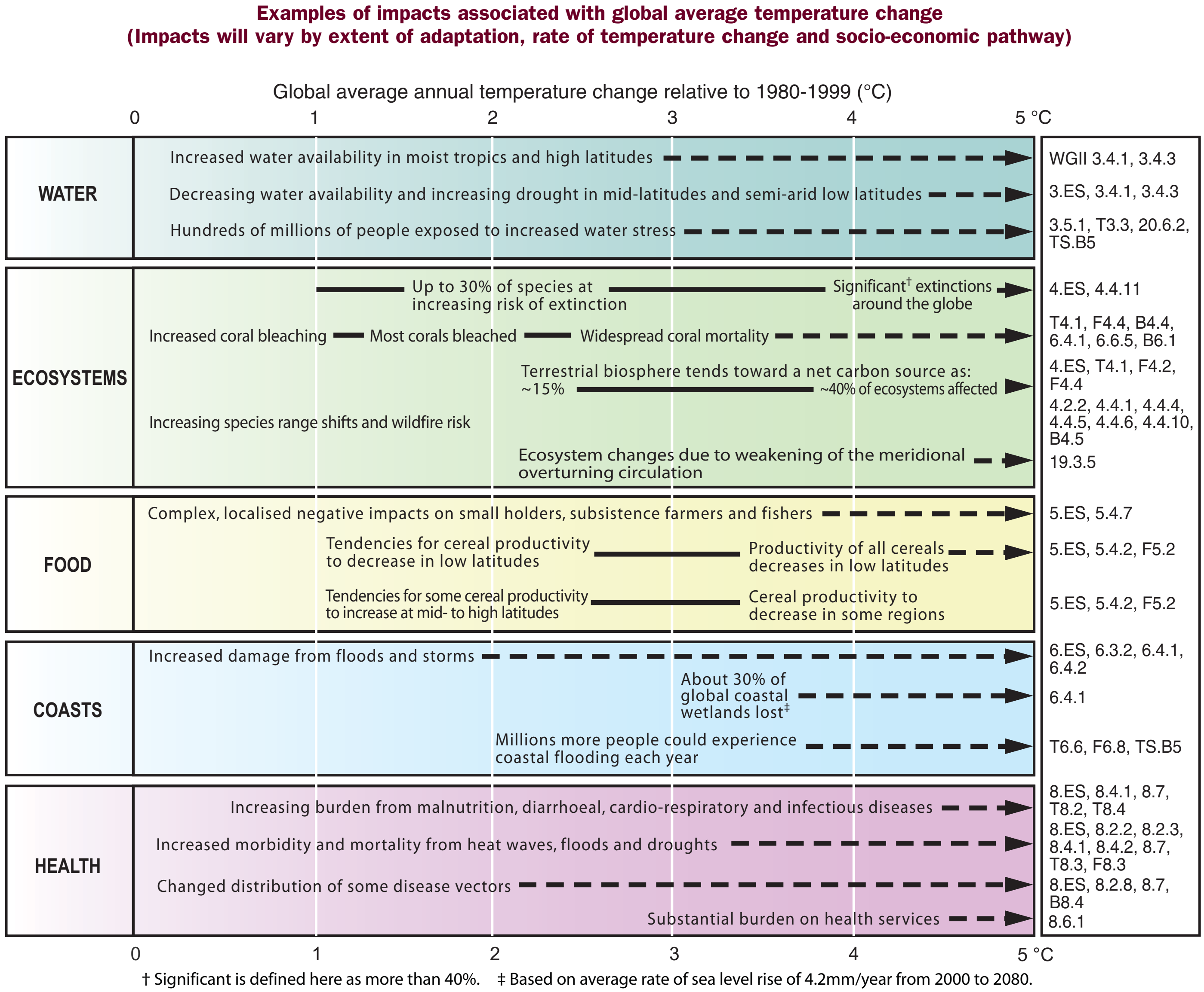
Europe

- Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods and more frequent coastal flooding and increased erosion (due to storminess and sea level rise). *{WGII 12.4, SPM}*
- Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60% under high emissions scenarios by 2080). *{WGII 12.4, SPM}*
- In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity. *{WGII 12.4, SPM}*
- Climate change is also projected to increase the health risks due to heat waves and the frequency of wildfires. *{WGII 12.4, SPM}*

Latin America

- By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. *{WGII 13.4, SPM}*
- There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. *{WGII 13.4, SPM}*
- Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase (*medium confidence*). *{WGII 13.4, Box TS.6}*
- Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation. *{WGII 13.4, SPM}*

[17] Unless stated explicitly, all entries are from WG II SPM text, and are either *very high confidence* or *high confidence* statements, reflecting different sectors (agriculture, ecosystems, water, coasts, health, industry and settlements). The WG II SPM refers to the source of the statements, timelines and temperatures. The magnitude and timing of impacts that will ultimately be realised will vary with the amount and rate of climate change, emissions scenarios, development pathways and adaptation.



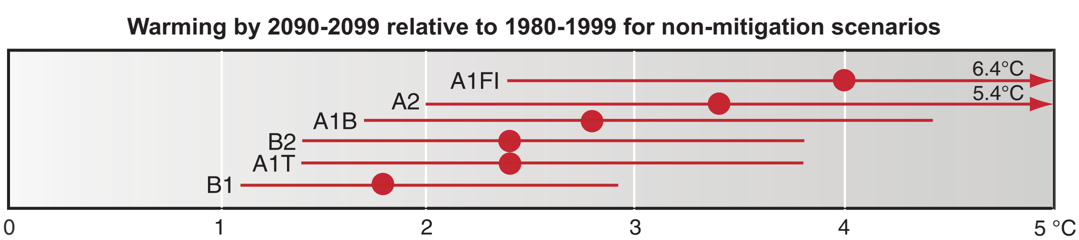


Figure 3.6. *Examples of impacts associated with global average temperature change.* ***Upper panel:*** *Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts; broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are* high. *The upper right panel gives the WG II references for the statements made in the upper left panel.** ***Lower panel:*** *Dots and bars indicate the best estimate and* likely *ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999. {WGI Figure SPM.5, 10.7; WGII Figure SPM.2; WGIII Table TS.2, Table 3.10}*

*Where ES = Executive Summary, T = Table, B = Box and F = Figure. Thus B4.5 indicates Box 4.5 in Chapter 4 and 3.5.1 indicates Section 3.5.1 in Chapter 3.

North America

- Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources. *{WGII 14.4, SPM}*
- In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5 to 20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilised water resources. *{WGII 14.4, SPM}*
- Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts. *{WGII 14.4, SPM}*
- Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution. *{WGII 14.4, SPM}*

Polar Regions

- The main projected biophysical effects are reductions in thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators. *{WGII 15.4, SPM}*
- For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed. *{WGII 15.4, SPM}*
- Detrimental impacts would include those on infrastructure and traditional indigenous ways of life. *{WGII 15.4, SPM}*
- In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered. {WGII 15.4, SPM}

Small Islands

- Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities. *{WGII 16.4, SPM}*
- Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources. *{WGII 16.4, SPM}*
- By mid-century, climate change is expected to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods. *{WGII 16.4, SPM}*
- With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands. *{WGII 16.4, SPM}*

3.3.3 Especially affected systems, sectors and regions

Some systems, sectors and regions are *likely* to be especially affected by climate change.[18] ***{WGII TS.4.5}***

Systems and sectors: *{WGII TS.4.5}*

- particular ecosystems:
  - terrestrial: tundra, boreal forest and mountain regions because of sensitivity to warming; mediterranean-type ecosystems because of reduction in rainfall; and tropical rainforests where precipitation declines
  - coastal: mangroves and salt marshes, due to multiple stresses
  - marine: coral reefs due to multiple stresses; the sea-ice biome because of sensitivity to warming
- water resources in some dry regions at mid-latitudes[19] and in the dry tropics, due to changes in rainfall and evapotranspiration, and in areas dependent on snow and ice melt
- agriculture in low latitudes, due to reduced water availability
- low-lying coastal systems, due to threat of sea level rise and increased risk from extreme weather events
- human health in populations with low adaptive capacity.

Regions: *{WGII TS.4.5}*

- the Arctic, because of the impacts of high rates of projected warming on natural systems and human communities
- Africa, because of low adaptive capacity and projected climate change impacts
- small islands, where there is high exposure of population and infrastructure to projected climate change impacts
- Asian and African megadeltas, due to large populations and high exposure to sea level rise, storm surges and river flooding.

Within other areas, even those with high incomes, some people (such as the poor, young children and the elderly) can be particularly at risk, and also some areas and some activities. *{WGII 7.1, 7.2, 7.4, 8.2, 8.4, TS.4.5}*

3.3.4 Ocean acidification

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO_2 concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species. *{WGI SPM; WGII SPM}*

3.3.5 Extreme events

Altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems (Table 3.2). ***{WGII SPM}***

Examples for selected extremes and sectors are shown in Table 3.2.

[18] Identified on the basis of expert judgement of the assessed literature and considering the magnitude, timing and projected rate of climate change, sensitivity and adaptive capacity.

[19] Including arid and semi-arid regions.

***Table 3.2.** Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21st century. These do not take into account any changes or developments in adaptive capacity. The likelihood estimates in column two relate to the phenomena listed in column one. {WGII Table SPM.1}*

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems *{WGII 4.4, 5.4}*	Water resources *{WGII 3.4}*	Human health *{WGII 8.2, 8.4}*	Industry, settlement and society *{WGII 7.4}*
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	*Virtually certain*[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	*Very likely*	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	*Very likely*	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding: pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	*Likely*	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	*Likely*	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (excludes tsunamis)[c]	*Likely*[d]	Salinisation of irrigation water, estuaries and fresh-water systems	Decreased fresh-water availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Notes:
a) See WGI Table 3.7 for further details regarding definitions.
b) Warming of the most extreme days and nights each year.
c) Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
d) In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. The effect of changes in regional weather systems on sea level extremes has not been assessed. *{WGI 10.6}*

3.4 Risk of abrupt or irreversible changes

Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change. ***{WGII 12.6, 19.3, 19.4, SPM}***

Abrupt climate change on decadal time scales is normally thought of as involving ocean circulation changes. In addition on longer time scales, ice sheet and ecosystem changes may also play a role. If a large-scale abrupt climate change were to occur, its impact could be quite high (see Topic 5.2). *{WGI 8.7, 10.3, 10.7; WGII 4.4, 19.3}*

Partial loss of ice sheets on polar land and/or the thermal expansion of seawater over very long time scales could imply metres of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying

islands. Current models project that such changes would occur over very long time scales (millennial) if a global temperature increase of 1.9 to 4.6°C (relative to pre-industrial) were to be sustained. Rapid sea level rise on century time scales cannot be excluded. *{SYR 3.2.3; WGI 6.4, 10.7; WGII 19.3, SPM}*

Climate change is *likely* to lead to some irreversible impacts. There is *medium confidence* that approximately 20 to 30% of species assessed so far are *likely* to be at increased risk of extinction if increases in global average warming exceed 1.5 to 2.5°C (relative to 1980-1999). As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40 to 70% of species assessed) around the globe. *{WGII 4.4, Figure SPM.2}*

Based on current model simulations, it is *very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century; nevertheless temperatures in the region are projected to increase. It is *very unlikely* that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence. *{WGI 10.3, 10.7; WGII Figure, Table TS.5, SPM.2}*

Impacts of large-scale and persistent changes in the MOC are *likely* to include changes in marine ecosystem productivity, fisheries, ocean CO_2 uptake, oceanic oxygen concentrations and terrestrial vegetation. Changes in terrestrial and ocean CO_2 uptake may feed back on the climate system. *{WGII 12.6, 19.3, Figure SPM.2}*

4

Adaptation and mitigation options and responses, and the inter-relationship with sustainable development, at global and regional levels

4.1 Responding to climate change

Societies can respond to climate change by adapting to its impacts and by reducing GHG emissions (mitigation), thereby reducing the rate and magnitude of change. This Topic focuses on adaptation and mitigation options that can be implemented over the next two to three decades, and their inter-relationship with sustainable development. These responses can be complementary. Topic 5 addresses their complementary roles on a more conceptual basis over a longer timeframe.

The capacity to adapt and mitigate is dependent on socio-economic and environmental circumstances and the availability of information and technology[20]. However, much less information is available about the costs and effectiveness of adaptation measures than about mitigation measures. *{WGII 17.1, 17.3; WGIII 1.2}*

4.2 Adaptation options

Adaptation can reduce vulnerability, both in the short and the long term. ***{WGII 17.2, 18.1, 18.5, 20.3, 20.8}***

Vulnerability to climate change can be exacerbated by other stresses. These arise from, for example, current climate hazards, poverty, unequal access to resources, food insecurity, trends in economic globalisation, conflict and incidence of diseases such as HIV/AIDS. *{WGII 7.2, 7.4, 8.3, 17.3, 20.3, 20.4, 20.7, SPM}*

Societies across the world have a long record of adapting and reducing their vulnerability to the impacts of weather- and climate-related events such as floods, droughts and storms. Nevertheless, additional adaptation measures will be required at regional and local levels to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades. However, adaptation alone is not expected to cope with all the projected effects of climate change, especially not over the long term as most impacts increase in magnitude. *{WGII 17.2, SPM; WGIII 1.2}*

A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood. Some planned adaptation is already occurring on a limited basis. Table 4.1 provides examples of planned adaptation options by sector. Many adaptation actions have multiple drivers, such as economic development and poverty alleviation, and are embedded within broader development, sectoral, regional and local planning initiatives such as water resources planning, coastal defence and disaster risk reduction strategies. Examples of this approach are the Bangladesh National Water Management Plan and the coastal defence plans of The Netherlands and Norway, which incorporate specific climate change scenarios. *{WGII 1.3, 5.5.2, 11.6, 17.2}*

Comprehensive estimates of the costs and benefits of adaptation at the global level are limited in number. However, the number of adaptation cost and benefit estimates at the regional and project levels for impacts on specific sectors, such as agriculture, energy demand for heating and cooling, water resources management and infrastructure, is growing. Based on these studies there is *high confidence* that there are viable adaptation options that can be implemented in some of these sectors at low cost and/or with high benefit-cost ratios. Empirical research also suggests that higher benefit-cost ratios can be achieved by implementing some adaptation measures at an early stage compared to retrofitting long-lived infrastructure at a later date. *{WGII 17.2}*

Adaptive capacity is intimately connected to social and economic development, but it is not evenly distributed across and within societies. ***{WGII 7.1, 7.2, 7.4, 17.3}***

The capacity to adapt is dynamic and is influenced by a society's productive base, including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology. It is also affected by multiple climate and non-climate stresses, as well as development policy. *{WGII 17.3}*

Recent studies reaffirm the TAR finding that adaptation will be vital and beneficial. However, financial, technological, cognitive, behavioural, political, social, institutional and cultural constraints limit both the implementation and effectiveness of adaptation measures. Even societies with high adaptive capacity remain vulnerable to climate change, variability and extremes. For example, a heat wave in 2003 caused high levels of mortality in European cities (especially among the elderly), and Hurricane Katrina in 2005 caused large human and financial costs in the United States. *{WGII 7.4, 8.2, 17.4}*

[20] Technology is defined as the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ('software', know-how for production and use of artefacts).

Table 4.1. *Selected examples of planned adaptation by sector.*

Sector	Adaptation option/strategy	Underlying policy framework	Key constraints and opportunities to implementation (Normal font = constraints; *italics = opportunities*)
Water {WGII, 5.5, 16.4; Tables 3.5, 11.6,17.1}	Expanded rainwater harvesting; water storage and conservation techniques; water reuse; desalination; water-use and irrigation efficiency	National water policies and integrated water resources management; water-related hazards management	Financial, human resources and physical barriers; *integrated water resources management; synergies with other sectors*
Agriculture {WGII 10.5, 13.5; Table 10.8}	Adjustment of planting dates and crop variety; crop relocation; improved land management, e.g. erosion control and soil protection through tree planting	R&D policies; institutional reform; land tenure and land reform; training; capacity building; crop insurance; financial incentives, e.g. subsidies and tax credits	Technological and financial constraints; access to new varieties; markets; *longer growing season in higher latitudes; revenues from 'new' products*
Infrastructure/ settlement (including coastal zones) {WGII 3.6, 11.4; Tables 6.11, 17.1}	Relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural barriers	Standards and regulations that integrate climate change considerations into design; land-use policies; building codes; insurance	Financial and technological barriers; availability of relocation space; *integrated policies and management; synergies with sustainable development goals*
Human health {WGII 14.5, Table 10.8}	Heat-health action plans; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation	Public health policies that recognise climate risk; strengthen health services; regional and international cooperation	Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; *upgraded health services; improved quality of life*
Tourism {WGII 12.5, 15.5, 17.5; Table 17.1}	Diversification of tourism attractions and revenues; shifting ski slopes to higher altitudes and glaciers; artificial snow-making	Integrated planning (e.g. carrying capacity; linkages with other sectors); financial incentives, e.g. subsidies and tax credits	Appeal/marketing of new attractions; financial and logistical challenges; potential adverse impact on other sectors (e.g. artificial snow-making may increase energy use); *revenues from 'new' attractions; involvement of wider group of stakeholders*
Transport {WGII 7.6, 17.2}	Realignment/relocation; design standards and planning for roads, rail and other infrastructure to cope with warming and drainage	Integrating climate change considerations into national transport policy; investment in R&D for special situations, e.g. permafrost areas	Financial and technological barriers; availability of less vulnerable routes; *improved technologies and integration with key sectors (e.g. energy)*
Energy {WGII 7.4, 16.2}	Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources; reduced dependence on single sources of energy	National energy policies, regulations, and fiscal and financial incentives to encourage use of alternative sources; incorporating climate change in design standards	Access to viable alternatives; financial and technological barriers; acceptance of new technologies; *stimulation of new technologies; use of local resources*

Note:
Other examples from many sectors would include early warning systems.

4.3 Mitigation options

Both bottom-up and top-down studies[21] indicate that there is *high agreement* and *much evidence* of substantial economic potential[21] for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels. *{WGIII 11.3, SPM}*

Figure 4.1 compares global economic mitigation potential in 2030 with the projected emissions increase from 2000 to 2030. Bottom-up studies suggest that mitigation opportunities with net negative costs[22] have the potential to reduce emissions by about 6 $GtCO_2$-eq/yr in 2030. Realising these requires dealing with implementation barriers. The economic mitigation potential, which is generally greater than the market mitigation potential, can only be achieved when adequate policies are in place and barriers removed.[21] *{WGIII 11.3, SPM}*

Sectoral estimates of economic mitigation potential and marginal costs derived from bottom-up studies corrected for double counting of mitigation potential are shown in Figure 4.2. While top-down and bottom-up studies are in line at the global level, there are considerable differences at the sectoral level. *{WGIII 11.3, SPM}*

No single technology can provide all of the mitigation potential in any sector. Table 4.2 lists selected examples of key technologies, policies, constraints and opportunities by sector. *{WGIII SPM}*

Future energy infrastructure investment decisions, expected to total over US$20 trillion[23] between 2005 and 2030, will have long-term impacts on GHG emissions, because of the long lifetimes of energy plants and other infrastructure capital stock. The widespread diffusion of low-carbon technologies may take many decades, even if early investments in these technologies are made attractive. Initial estimates show that returning global energy-related CO_2 emissions to 2005 levels by 2030 would require a large shift in the pattern of investment, although the net additional investment required ranges from negligible to 5 to 10%. *{WGIII 4.1, 4.4, 11.6, SPM}*

Comparison between global economic mitigation potential and projected emissions increase in 2030

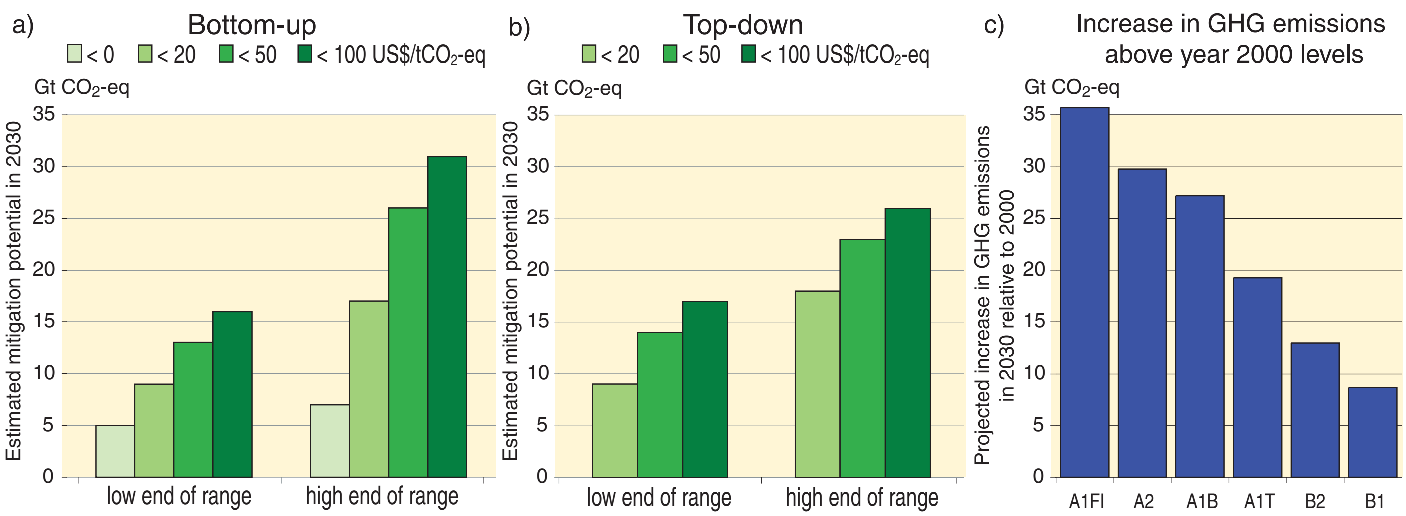


Figure 4.1. *Global economic mitigation potential in 2030 estimated from bottom-up (Panel a) and top-down (Panel b) studies, compared with the projected emissions increases from SRES scenarios relative to year 2000 GHG emissions of 40.8 $GtCO_2$-eq (Panel c). Note: GHG emissions in 2000 are exclusive of emissions of decay of above-ground biomass that remains after logging and deforestation and from peat fires and drained peat soils, to ensure consistency with the SRES emissions results. {WGIII Figures SPM.4, SPM.5a, SPM.5b}*

[21] The concept of **'mitigation potential'** has been developed to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced). Mitigation potential is further differentiated in terms of 'market mitigation potential' and 'economic mitigation potential'.

Market mitigation potential is the mitigation potential based on private costs and private discount rates (reflecting the perspective of private consumers and companies), which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake.

Economic mitigation potential is the mitigation potential that takes into account social costs and benefits and social discount rates (reflecting the perspective of society; social discount rates are lower than those used by private investors), assuming that market efficiency is improved by policies and measures and barriers are removed.

Mitigation potential is estimated using different types of approaches. ***Bottom-up studies*** are based on assessment of mitigation options, emphasising specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. ***Top-down studies*** assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

[22] Net negative costs (no regrets opportunities) are defined as those options whose benefits such as reduced energy costs and reduced emissions of local/regional pollutants equal or exceed their costs to society, excluding the benefits of avoided climate change.

[23] 20 trillion = 20,000 billion = 20×10^{12}

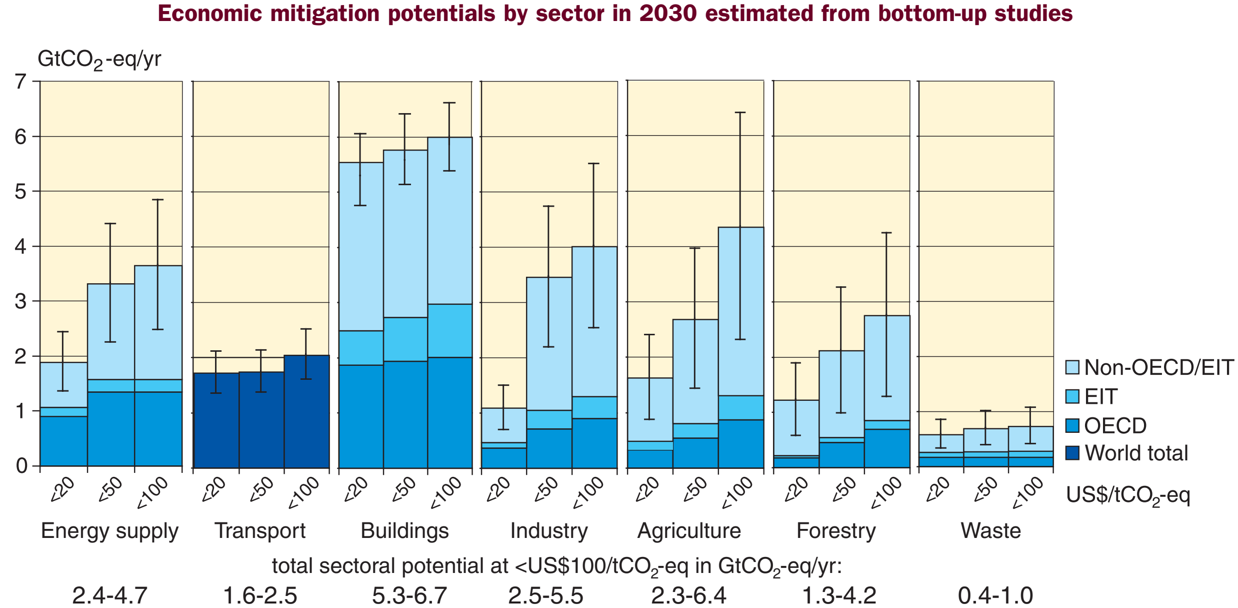


Figure 4.2. *Estimated economic mitigation potential by sector and region using technologies and practices expected to be available in 2030. The potentials do not include non-technical options such as lifestyle changes. {WGIII Figure SPM.6}*

Notes:

a) The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.
b) The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.
c) Sectors used different baselines. For industry the SRES B2 baseline was taken, for energy supply and transport the World Energy Outlook (WEO) 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste-specific baseline; agriculture and forestry used baselines that mostly used B2 driving forces.
d) Only global totals for transport are shown because international aviation is included.
e) Categories excluded are non-CO_2 emissions in buildings and transport, part of material efficiency options, heat production and cogeneration in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, and fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10 to 15%.

While studies use different methodologies, there is *high agreement* and *much evidence* that in all analysed world regions near-term health co-benefits from reduced air pollution, as a result of actions to reduce GHG emissions, can be substantial and may offset a substantial fraction of mitigation costs. ***{WGIII 11.8, SPM}***

Energy efficiency and utilisation of renewable energy offer synergies with sustainable development. In least developed countries, energy substitution can lower mortality and morbidity by reducing indoor air pollution, reduce the workload for women and children and decrease the unsustainable use of fuelwood and related deforestation. *{WGIII 11.8, 11.9, 12.4}*

Literature since the TAR confirms with *high agreement* and *medium evidence* that there may be effects from Annex I countries' action on the global economy and global emissions, although the scale of carbon leakage remains uncertain. ***{WGIII 11.7, SPM}***

Fossil fuel exporting nations (in both Annex I and non-Annex I countries) may expect, as indicated in the TAR, lower demand and prices and lower GDP growth due to mitigation policies. The extent of this spillover depends strongly on assumptions related to policy decisions and oil market conditions. *{WGIII 11.7, SPM}*

Critical uncertainties remain in the assessment of carbon leakage. Most equilibrium modelling supports the conclusion in the TAR of economy-wide leakage from Kyoto action in the order of 5 to 20%, which would be less if competitive low-emissions technologies were effectively diffused. *{WGIII 11.7, SPM}*

There is also *high agreement* and *medium evidence* that changes in lifestyle and behaviour patterns can contribute to climate change mitigation across all sectors. Management practices can also have a positive role. ***{WGIII SPM}***

Examples that can have positive impacts on mitigation include changes in consumption patterns, education and training, changes in building occupant behaviour, transport demand management and management tools in industry. *{WGIII 4.1, 5.1, 6.7, 7.3, SPM}*

Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-GHG products, technologies and processes. ***{WGIII SPM}***

An effective carbon-price signal could realise significant mitigation potential in all sectors. Modelling studies show that global carbon prices rising to US\$20-80/tCO_2-eq by 2030 are consistent with stabilisation at around 550ppm CO_2-eq by 2100. For the same

Table 4.2 *Selected examples of key sectoral mitigation technologies, policies and measures, constraints and opportunities. {WGIII Tables SPM.3, SPM.7}*

Sector	Key mitigation technologies and practices currently commercially available. *Key mitigation technologies and practices projected to be commercialised before 2030 shown in italics.*	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities (Normal font = constraints; *italics = opportunities*)
Energy Supply {WGIII 4.3, 4.4}	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of carbon dioxide capture and storage (CCS) (e.g. storage of removed CO_2 from natural gas); *CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and wave energy, concentrating solar, and solar photovoltaics*	Reduction of fossil fuel subsidies; taxes or carbon charges on fossil fuels	Resistance by vested interests may make them difficult to implement
		Feed-in tariffs for renewable energy technologies; renewable energy obligations; producer subsidies	*May be appropriate to create markets for low-emissions technologies*
Transport {WGIII 5.4}	More fuel-efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning; *second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries*	Mandatory fuel economy; biofuel blending and CO_2 standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
		Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing	Effectiveness may drop with higher incomes
		Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport	*Particularly appropriate for countries that are building up their transportation systems*
Buildings {WGIII 6.5}	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycling of fluorinated gases; *integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings*	Appliance standards and labelling	Periodic revision of standards needed
		Building codes and certification	*Attractive for new buildings.* Enforcement can be difficult
		Demand-side management programmes	Need for regulations so that utilities may profit
		Public sector leadership programmes, including procurement	*Government purchasing can expand demand for energy-efficient products*
		Incentives for energy service companies (ESCOs)	*Success factor: Access to third party financing*
Industry {WGIII 7.5}	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO_2 gas emissions; and a wide array of process-specific technologies; *advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture*	Provision of benchmark information; performance standards; subsidies; tax credits	*May be appropriate to stimulate technology uptake.* Stability of national policy important in view of international competitiveness
		Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
		Voluntary agreements	Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry
Agriculture {WGIII 8.4}	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertiliser application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency; *improvements of crop yields*	Financial incentives and regulations for improved land management; maintaining soil carbon content; efficient use of fertilisers and irrigation	*May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation*
Forestry/forests {WGIII 9.4}	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use; *tree species improvement to increase biomass productivity and carbon sequestration; improved remote sensing technologies for analysis of vegetation/soil carbon sequestration potential and mapping land-use change*	Financial incentives (national and international) to increase forest area, to reduce deforestation and to maintain and manage forests; land-use regulation and enforcement	Constraints include lack of investment capital and land tenure issues. *Can help poverty alleviation.*
Waste {WGIII 10.4}	Landfill CH_4 recovery; waste incineration with energy recovery; composting of organic waste; controlled wastewater treatment; recycling and waste minimisation; *biocovers and biofilters to optimise CH_4 oxidation*	Financial incentives for improved waste and wastewater management	*May stimulate technology diffusion*
		Renewable energy incentives or obligations	Local availability of low-cost fuel
		Waste management regulations	Most effectively applied at national level with enforcement strategies

stabilisation level, studies since the TAR that take into account induced technological change may lower these price ranges to US$5-65/t$CO_2$-eq in 2030.[24] *{WGIII 3.3, 11.4, 11.5, SPM}*

There is *high agreement* and *much evidence* that a wide variety of national policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and an understanding of their interactions, but experience from implementation in various countries and sectors shows there are advantages and disadvantages for any given instrument. *{WGIII 13.2, SPM}*

Four main criteria are used to evaluate policies and instruments: environmental effectiveness, cost effectiveness, distributional effects including equity, and institutional feasibility. *{WGIII 13.2, SPM}*

General findings about the performance of policies are: *{WGIII 13.2, SPM}*

- ***Integrating climate policies in broader development policies*** makes implementation and overcoming barriers easier.
- ***Regulations and standards*** generally provide some certainty about emission levels. They may be preferable to other instruments when information or other barriers prevent producers and consumers from responding to price signals. However, they may not induce innovations and more advanced technologies.
- ***Taxes and charges*** can set a price for carbon, but cannot guarantee a particular level of emissions. Literature identifies taxes as an efficient way of internalising costs of GHG emissions.
- ***Tradable permits*** will establish a carbon price. The volume of allowed emissions determines their environmental effectiveness, while the allocation of permits has distributional consequences. Fluctuation in the price of carbon makes it difficult to estimate the total cost of complying with emission permits.
- ***Financial incentives*** (subsidies and tax credits) are frequently used by governments to stimulate the development and diffusion of new technologies. While economic costs are generally higher than for the instruments listed above, they are often critical to overcome barriers.
- ***Voluntary agreements*** between industry and governments are politically attractive, raise awareness among stakeholders and have played a role in the evolution of many national policies. The majority of agreements have not achieved significant emissions reductions beyond business as usual. However, some recent agreements, in a few countries, have accelerated the application of best available technology and led to measurable emission reductions.
- ***Information instruments*** (e.g. awareness campaigns) may positively affect environmental quality by promoting informed choices and possibly contributing to behavioural change, however, their impact on emissions has not been measured yet.
- ***Research, development and demonstration (RD&D)*** can stimulate technological advances, reduce costs and enable progress toward stabilisation.

Some corporations, local and regional authorities, NGOs and civil groups are adopting a wide variety of voluntary actions. These voluntary actions may limit GHG emissions, stimulate innovative policies and encourage the deployment of new technologies. On their own, they generally have limited impact on national- or regional-level emissions. *{WGIII 13.4, SPM}*

4.4 Relationship between adaptation and mitigation options and relationship with sustainable development

There is growing understanding of the possibilities to choose and implement climate response options in several sectors to realise synergies and avoid conflicts with other dimensions of sustainable development. *{WGIII SPM}*

Climate change policies related to energy efficiency and renewable energy are often economically beneficial, improve energy security and reduce local pollutant emissions. Reducing both loss of natural habitat and deforestation can have significant biodiversity, soil and water conservation benefits, and can be implemented in a socially and economically sustainable manner. Forestation and bioenergy plantations can restore degraded land, manage water runoff, retain soil carbon and benefit rural economies, but could compete with food production and may be negative for biodiversity, if not properly designed. *{WGII 20.3, 20.8; WGIII 4.5, 9.7, 12.3, SPM}*

There is growing evidence that decisions about macro-economic policy, agricultural policy, multilateral development bank lending, insurance practices, electricity market reform, energy security and forest conservation, for example, which are often treated as being apart from climate policy, can significantly reduce emissions (Table 4.3). Similarly, non-climate policies can affect adaptive capacity and vulnerability. *{WGII 20.3; WGIII SPM, 12.3}*

Both synergies and trade-offs exist between adaptation and mitigation options. *{WGII 18.4.3; WGIII 11.9)*

Examples of synergies include properly designed biomass production, formation of protected areas, land management, energy use in buildings, and forestry, but synergies are rather limited in other sectors. Potential trade-offs include increased GHG emissions due to increased consumption of energy related to adaptive responses. *{WGII 18.4.3, 18.5, 18.7, TS.5.2; WGIII 4.5, 6.9, 8.5, 9.5, SPM}*

[24] Studies on mitigation portfolios and macro-economic costs assessed in this report are based on top-down modelling. Most models use a global least-cost approach to mitigation portfolios, with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21st century. Costs are given for a specific point in time. Global modelled costs will increase if some regions, sectors (e.g. land use), options or gases are excluded. Global modelled costs will decrease with lower baselines, use of revenues from carbon taxes and auctioned permits, and if induced technological learning is included. These models do not consider climate benefits and generally also co-benefits of mitigation measures, or equity issues. Significant progress has been achieved in applying approaches based on induced technological change to stabilisation studies; however, conceptual issues remain. In the models that consider induced technological change, projected costs for a given stabilisation level are reduced; the reductions are greater at lower stabilisation level.

Table 4.3. *Integrating climate change considerations into development policies – selected examples in the area of mitigation. {WGIII 12.2.4.6}*

Selected sectors	Non-climate change policy instruments and actions	Potentially affects:
Macro-economy	Implement non-climate taxes/subsidies and/or other fiscal and regulatory policies that promote sustainable development	Total global GHG emissions
Forestry	Adoption of forest conservation and sustainable management practices	GHG emissions from deforestation
Electricity	Adoption of cost-effective renewables, demand-side management programmes, and transmission and distribution loss reduction	Electricity sector CO_2 emissions
Petroleum imports	Diversifying imported and domestic fuel mix and reducing economy's energy intensity to improve energy security	Emissions from crude oil and product imports
Insurance for building, transport sectors	Differentiated premiums, liability insurance exclusions, improved terms for green products	Transport and building sector GHG emissions
International finance	Country and sector strategies and project lending that reduces emissions	Emissions from developing countries

4.5 International and regional cooperation

There is *high agreement* and *much evidence* that notable achievements of the UNFCCC and its Kyoto Protocol are the establishment of a global response to the climate change problem, stimulation of an array of national policies, the creation of an international carbon market and the establishment of new institutional mechanisms that may provide the foundation for future mitigation efforts. Progress has also been made in addressing adaptation within the UNFCCC and additional initiatives have been suggested. *{WGII 18.7; WGIII 13.3, SPM}*

The impact of the Protocol's first commitment period relative to global emissions is projected to be limited. Its economic impacts on participating Annex-B countries are projected to be smaller than presented in the TAR, which showed 0.2 to 2% lower GDP in 2012 without emissions trading and 0.1 to 1.1% lower GDP with emissions trading among Annex-B countries. To be more environmentally effective, future mitigation efforts would need to achieve deeper reductions covering a higher share of global emissions (see Topic 5). *{WGIII 1.4, 11.4, 13.3, SPM}*

The literature provides *high agreement* and *much evidence* of many options for achieving reductions of global GHG emissions at the international level through cooperation. It also suggests that successful agreements are environmentally effective, cost-effective, incorporate distributional considerations and equity, and are institutionally feasible. *{WGIII 13.3, SPM}*

Greater cooperative efforts to reduce emissions will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness. Improving and expanding the scope of market mechanisms (such as emission trading, Joint Implementation and Clean Development Mechanism) could reduce overall mitigation costs. *{WGIII 13.3, SPM}*

Efforts to address climate change can include diverse elements such as emissions targets; sectoral, local, sub-national and regional actions; RD&D programmes; adopting common policies; implementing development-oriented actions; or expanding financing instruments. These elements can be implemented in an integrated fashion, but comparing the efforts made by different countries quantitatively would be complex and resource intensive. *{WGIII 13.3, SPM}*

Actions that could be taken by participating countries can be differentiated both in terms of when such action is undertaken, who participates and what the action will be. Actions can be binding or non-binding, include fixed or dynamic targets, and participation can be static or vary over time. *{WGIII 13.3, SPM}*

5

The long-term perspective: scientific and socio-economic aspects relevant to adaptation and mitigation, consistent with the objectives and provisions of the Convention, and in the context of sustainable development

5.1 Risk management perspective

Responding to climate change involves an iterative risk management process that includes both mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity and attitudes to risk. *{WGII 20. 9, SPM; WGIII SPM}*

Risk management techniques can explicitly accommodate sectoral, regional and temporal diversity, but their application requires information about not only impacts resulting from the most likely climate scenarios, but also impacts arising from lower-probability but higher-consequence events and the consequences of proposed policies and measures. Risk is generally understood to be the product of the likelihood of an event and its consequences. Climate change impacts depend on the characteristics of natural and human systems, their development pathways and their specific locations. *{SYR 3.3, Figure 3.6; WGII 20.2, 20.9, SPM; WGIII 3.5, 3.6, SPM}*

5.2 Key vulnerabilities, impacts and risks – long-term perspectives

The five 'reasons for concern' identified in the TAR are now assessed to be stronger with many risks identified with higher confidence. Some are projected to be larger or to occur at lower increases in temperature. This is due to (1) better understanding of the magnitude of impacts and risks associated with increases in global average temperature and GHG concentrations, including vulnerability to present-day climate variability, (2) more precise identification of the circumstances that make systems, sectors, groups and regions especially vulnerable and (3) growing evidence that the risk of very large impacts on multiple century time scales would continue to increase as long as GHG concentrations and temperature continue to increase. Understanding about the relationship between impacts (the basis for 'reasons for concern' in the TAR) and vulnerability (that includes the ability to adapt to impacts) has improved. *{WGII 4.4, 5.4, 19.ES, 19.3.7, TS.4.6; WGIII 3.5, SPM}*

The TAR concluded that vulnerability to climate change is a function of exposure, sensitivity and adaptive capacity. Adaptation can reduce sensitivity to climate change while mitigation can reduce the exposure to climate change, including its rate and extent. Both conclusions are confirmed in this assessment. *{WGII 20.2, 20.7.3}*

No single metric can adequately describe the diversity of key vulnerabilities or support their ranking. A sample of relevant impacts is provided in Figure 3.6. The estimation of key vulnerabilities in any system, and damage implied, will depend on exposure (the rate and magnitude of climate change), sensitivity, which is determined in part and where relevant by development status, and adaptive capacity. Some key vulnerabilities may be linked to thresholds; in some cases these may cause a system to shift from one state to another, whereas others have thresholds that are defined subjectively and thus depend on societal values. *{WGII 19.ES, 19.1}*

The five 'reasons for concern' that were identified in the TAR were intended to synthesise information on climate risks and key vulnerabilities and to "aid readers in making their own determination" about risk. These remain a viable framework to consider key vulnerabilities, and they have been updated in the AR4. *{TAR WGII Chapter 19; WGII SPM}*

- ***Risks to unique and threatened systems.*** There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR as warming proceeds. There is *medium confidence* that approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C over 1980-1999 levels. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels (about 1.5 to 2.5°C above pre-indus-

Key Vulnerabilities and Article 2 of the UNFCCC

Article 2 of the UNFCCC states:

"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Determining what constitutes "dangerous anthropogenic interference with the climate system" in relation to Article 2 of the UNFCCC involves value judgements. Science can support informed decisions on this issue, including by providing criteria for judging which vulnerabilities might be labelled 'key'. *{SYR 3.3, WGII 19.ES}*

Key vulnerabilities[25] may be associated with many climate-sensitive systems, including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets and modes of oceanic and atmospheric circulation. *{WGII 19.ES}*

More specific information is now available across the regions of the world concerning the nature of future impacts, including for some places not covered in previous assessments. *{WGII SPM}*

[25] Key Vulnerabilities can be identified based on a number of criteria in the literature, including magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts.

trial) poses significant risks to many unique and threatened systems including many biodiversity hotspots. Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals. Increasing vulnerability of Arctic indigenous communities and small island communities to warming is projected. *{SYR 3.3, 3.4, Figure 3.6, Table 3.2; WGII 4.ES, 4.4, 6.4, 14.4.6, 15.ES, 15.4, 15.6, 16.ES, 16.2.1, 16.4, Table 19.1, 19.3.7, TS.5.3, Figure TS.12, Figure TS.14}*

- ***Risks of extreme weather events.*** Responses to some recent extreme climate events reveal higher levels of vulnerability in both developing and developed countries than was assessed in the TAR. There is now higher confidence in the projected increases in droughts, heat waves and floods, as well as their adverse impacts. As summarised in Table 3.2, increases in drought, heat waves and floods are projected in many regions and would have mostly adverse impacts, including increased water stress and wild fire frequency, adverse effects on food production, adverse health effects, increased flood risk and extreme high sea level, and damage to infrastructure. *{SYR 3.2, 3.3, Table 3.2; WGI 10.3, Table SPM.2; WGII 1.3, 5.4, 7.1, 7.5, 8.2, 12.6, 19.3, Table 19.1, Table SPM.1}*
- ***Distribution of impacts and vulnerabilities.*** There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change and are frequently the most susceptible to climate-related damages, especially when they face multiple stresses. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing but also in developed countries. There is greater confidence in the projected regional patterns of climate change (see Topic 3.2) and in the projections of regional impacts, enabling better identification of particularly vulnerable systems, sectors and regions (see Topic 3.3). Moreover, there is increased evidence that low-latitude and less-developed areas generally face greater risk, for example in dry areas and megadeltas. New studies confirm that Africa is one of the most vulnerable continents because of the range of projected impacts, multiple stresses and low adaptive capacity. Substantial risks due to sea level rise are projected particularly for Asian megadeltas and for small island communities. *{SYR 3.2, 3.3, 5.4; WGI 11.2-11.7, SPM; WGII 3.4.3, 5.3, 5.4, Boxes 7.1 and 7.4, 8.1.1, 8.4.2, 8.6.1.3, 8.7, 9.ES, Table 10.9, 10.6, 16.3, 19.ES, 19.3, Table 19.1, 20.ES, TS.4.5, TS.5.4, Tables TS.1, TS.3, TS.4, SPM}*
- ***Aggregate impacts.*** Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude and therefore sooner than was assessed in the TAR. It is *likely* that there will be higher damages for larger magnitudes of global temperature increase than estimated in the TAR, and the net costs of impacts of increased warming are projected to increase over time. Aggregate impacts have also been quantified in other metrics (see Topic 3.3): for example, climate change over the next century is *likely* to adversely affect hundreds of millions of people through increased coastal flooding, reductions in water supplies, increased malnutrition and increased health impacts. *{SYR 3.3, Figure 3.6; WGII 19.3.7, 20.7.3, TS.5.3}*
- ***Risks of large-scale singularities.***[26] As discussed in Topic 3.4, during the current century, a large-scale abrupt change in the meridional overturning circulation is *very unlikely*. There is *high confidence* that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20th century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales. This is because ice dynamical processes seen in recent observations but not fully included in ice sheet models assessed in the AR4 could increase the rate of ice loss. Complete deglaciation of the Greenland ice sheet would raise sea level by 7m and could be irreversible. *{SYR 3.4; WGI 10.3, Box 10.1; WGII 19.3.7, SPM}*

5.3 Adaptation and mitigation

There is *high confidence* that neither adaptation nor mitigation alone can avoid all climate change impacts. Adaptation is necessary both in the short term and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs that are not fully understood. Adaptation and mitigation can complement each other and together can significantly reduce the risks of climate change. ***{WGII 4.ES, TS 5.1, 18.4, 18.6, 20.7, SPM; WGIII 1.2, 2.5, 3.5, 3.6}***

Adaptation will be ineffective for some cases such as natural ecosystems (e.g. loss of Arctic sea ice and marine ecosystem viability), the disappearance of mountain glaciers that play vital roles in water storage and supply, or adaptation to sea level rise of several metres[27]. It will be less feasible or very costly in many cases for the projected climate change beyond the next several decades (such as deltaic regions and estuaries). There is *high confidence* that the ability of many ecosystems to adapt naturally will be exceeded this century. In addition, multiple barriers and constraints to effective adaptation exist in human systems (see Topic 4.2). *{SYR 4.2; WGII 17.4.2, 19.2, 19.4.1}*

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. Reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is not possible, or will only be available at very high social, environmental and economic costs. *{WGII 18.1, SPM}*

[26] See glossary

[27] While it is technically possible to adapt to several metres of sea level rise, the resources required are so unevenly distributed that in reality this risk is outside the scope of adaptation. {WGII 17.4.2, 19.4.1}

Efforts to mitigate GHG emissions to reduce the rate and magnitude of climate change need to account for inertia in the climate and socio-economic systems. ***{SYR 3.2; WGI 10.3, 10.4, 10.7, SPM; WGIII 2.3.4}***

After GHG concentrations are stabilised, the rate at which the global average temperature increases is expected to slow within a few decades. Small increases in global average temperature could still be expected for several centuries. Sea level rise from thermal expansion would continue for many centuries at a rate that eventually decreases from that reached before stabilisation, due to ongoing heat uptake by oceans. *{SYR 3.2, WGI 10.3, 10.4, 10.7, SPM}*

Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. Even though benefits of mitigation measures in terms of avoided climate change would take several decades to materialise, mitigation actions begun in the short term would avoid locking in both long-lived carbon intensive infrastructure and development pathways, reduce the rate of climate change and reduce the adaptation needs associated with higher levels of warming. *{WGII 18.4, 20.6, 20.7, SPM; WGIII 2.3.4, 3.4, 3.5, 3.6, SPM}*

5.4 Emission trajectories for stabilisation

In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter.[28] The lower the stabilisation level, the more quickly this peak and decline would need to occur (Figure 5.1).[29] ***{WGIII 3.3, 3.5, SPM}***

Advances in modelling since the TAR permit the assessment of multi-gas mitigation strategies for exploring the attainability and costs for achieving stabilisation of GHG concentrations. These scenarios explore a wider range of future scenarios, including lower levels of stabilisation, than reported in the TAR. *{WGIII 3.3, 3.5, SPM}*

Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels (Table 5.1 and Figure 5.1). ***{WGIII 3.5, SPM}***

Table 5.1 summarises the required emission levels for different groups of stabilisation concentrations and the resulting equilibrium

CO_2 emissions and equilibrium temperature increases for a range of stabilisation levels

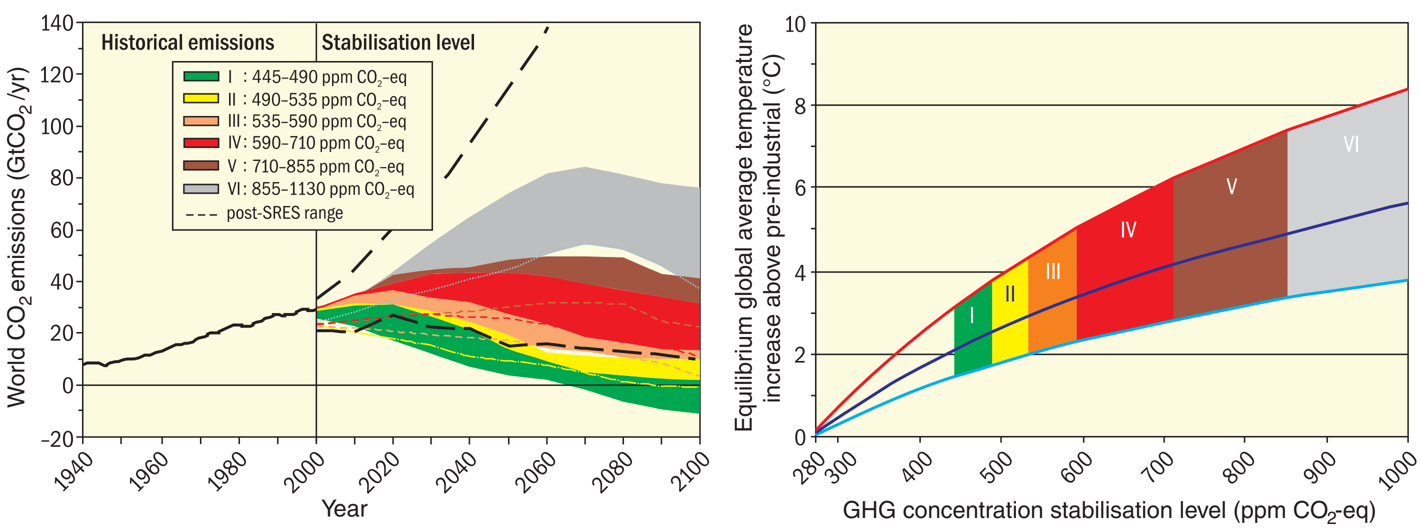


Figure 5.1. Global CO_2 emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely *equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). The right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) 'best estimate' climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of* likely *range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of* likely *range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO_2-only and multigas scenarios and correspond to the 10^{th} to 90^{th} percentile of the full scenario distribution. Note: CO_2 emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils. {WGIII Figures SPM.7 and SPM.8}*

[28] Peaking means that the emissions need to reach a maximum before they decline later.

[29] For the lowest mitigation scenario category assessed, emissions would need to peak by 2015 and for the highest by 2090 (see Table 5.1). Scenarios that use alternative emission pathways show substantial differences on the rate of global climate change. {WGII 19.4}

Table 5.1. *Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.[a] {WGI 10.7; WGIII Table TS.2, Table 3.10, Table SPM.5}*

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005=375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d,e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:
a) The emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2.3).
b) Atmospheric CO_2 concentrations were 379ppm in 2005. The best estimate of total CO_2-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO_2-eq.
c) Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios (see Figure 2.1).
d) The best estimate of climate sensitivity is 3°C.
e) Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150 (see also Footnote 30).
f) Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low-resolution AOGCM and several EMICs based on the best estimate of 3°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6m per degree Celsius of global average warming above pre-industrial. (AOGCM refers to Atmosphere-Ocean General Circulation Model and EMICs to Earth System Models of Intermediate Complexity.)

global average temperature increases, using the 'best estimate' of climate sensitivity (see Figure 5.1 for the *likely* range of uncertainty). Stabilisation at lower concentration and related equilibrium temperature levels advances the date when emissions need to peak and requires greater emissions reductions by 2050.[30] Climate sensitivity is a key uncertainty for mitigation scenarios that aim to meet specific temperature levels. The timing and level of mitigation to reach a given temperature stabilisation level is earlier and more stringent if climate sensitivity is high than if it is low. *{WGIII 3.3, 3.4, 3.5, 3.6, SPM}*

Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21st century (Table 5.1). If GHG and aerosol concentrations had been stabilised at year 2000 levels, thermal expansion alone would be expected to lead to further sea level rise of 0.3 to 0.8m. The eventual contributions from Greenland ice sheet loss could be several metres, and larger than from thermal expansion, should warming in excess of 1.9 to 4.6°C above pre-industrial be sustained over many centuries. These long-term consequences would have major implications for world coastlines. The long time scale of thermal expansion and ice sheet response to warming imply that mitigation strategies that seek to stabilise GHG concentrations (or radiative forcing) at or above present levels do not stabilise sea level for many centuries. *{WG1 10.7}*

Feedbacks between the carbon cycle and climate change affect the required mitigation and adaptation response to climate change. Climate-carbon cycle coupling is expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms (see Topics 2.3 and 3.2.1), but mitigation studies have not yet incorporated the full range of these feedbacks. As a consequence, the emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed in Table 5.1 might be underestimated. Based on current understanding of climate-carbon cycle feedbacks, model studies suggest that stabilising CO_2 concentrations at, for example, 450ppm[31] could require cumulative emissions over the 21st century to be less than 1800 [1370 to 2200] $GtCO_2$, which is about 27% less than the 2460 [2310 to 2600] $GtCO_2$ determined without consideration of carbon cycle feedbacks. *{SYR 2.3, 3.2.1; WGI 7.3, 10.4, SPM}*

[30] Estimates for the evolution of temperature over the course of this century are not available in the AR4 for the stabilisation scenarios. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For the much lower stabilisation scenarios (category I and II, Figure 5.1), the equilibrium temperature may be reached earlier.

[31] To stabilise at 1000ppm CO_2, this feedback could require that cumulative emissions be reduced from a model average of approximately 5190 [4910 to 5460] $GtCO_2$ to approximately 4030 [3590 to 4580] $GtCO_2$. {WGI 7.3, 10.4, SPM}

5.5 Technology flows and development

There is *high agreement* and *much evidence* that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and addressing related barriers. ***{WGIII SPM}***

Worldwide deployment of low-GHG emission technologies as well as technology improvements through public and private RD&D would be required for achieving stabilisation targets as well as cost reduction.[32] Figure 5.2 gives illustrative examples of the contribution of the portfolio of mitigation options. The contribution of different technologies varies over time and region and depends on the baseline development path, available technologies and relative costs, and the analysed stabilisation levels. Stabilisation at the lower of the assessed levels (490 to 540ppm CO_2-eq) requires early investments and substantially more rapid diffusion and commercialisation of advanced low-emissions technologies over the next decades (2000-2030) and higher contributions across abatement options in the long term (2000-2100). This requires that barriers to development, acquisition, deployment and diffusion of technologies are effectively addressed with appropriate incentives. *{WGIII 2.7, 3.3, 3.4, 3.6, 4.3, 4.4, 4.6, SPM}*

Without sustained investment flows and effective technology transfer, it may be difficult to achieve emission reduction at a significant scale. Mobilising financing of incremental costs of low-carbon technologies is important. *{WGIII 13.3, SPM}*

There are large uncertainties concerning the future contribution of different technologies. However, all assessed stabilisation scenarios concur that 60 to 80% of the reductions over the course of the century would come from energy supply and use and industrial processes. Including non-CO_2 and CO_2 land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Energy efficiency plays a key role across many scenarios for most regions and time scales. For lower stabilisation levels, scenarios put more emphasis on the use of low-carbon energy sources, such as renewable energy, nuclear power and the use of CO_2 capture and storage (CCS). In these scenarios, improvements of carbon intensity of energy supply and the whole economy needs to be much faster than in the past (Figure 5.2). *{WGIII 3.3, 3.4, TS.3, SPM}*

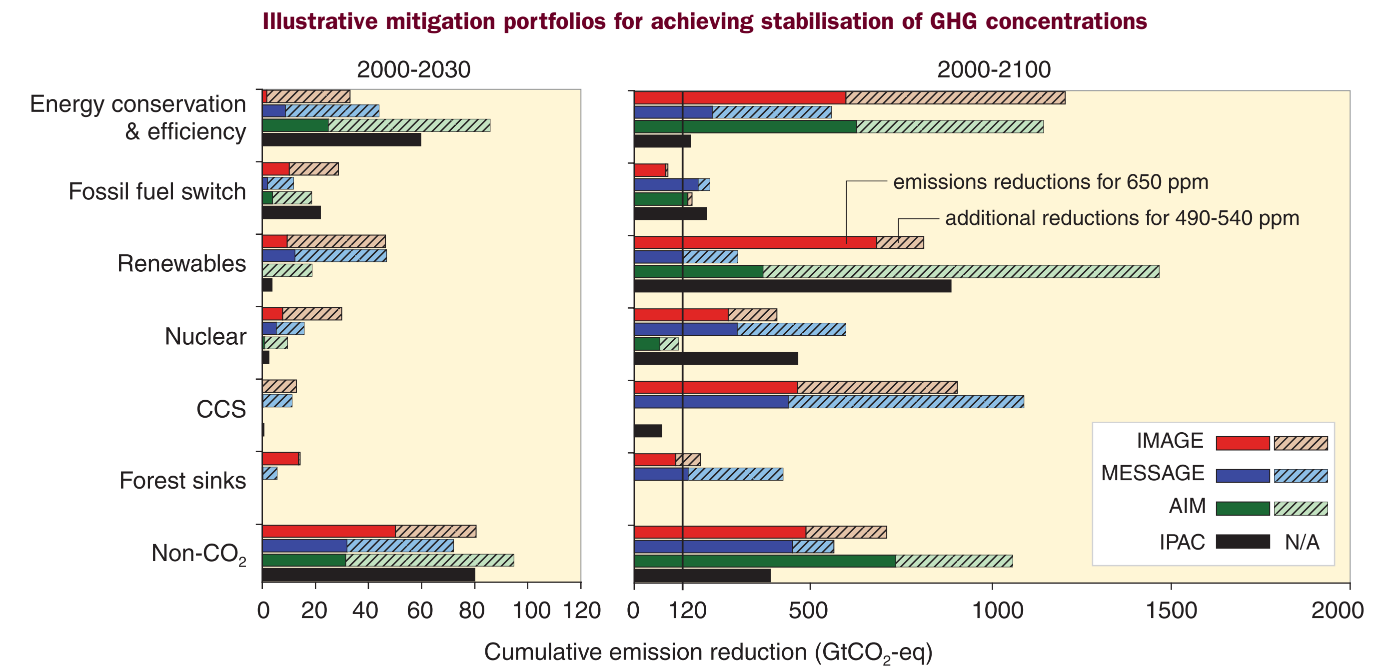


***Figure 5.2** Cumulative emissions reductions for alternative mitigation measures for 2000-2030 (left-hand panel) and for 2000-2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilisation at low (490 to 540ppm CO_2-eq) and intermediate levels (650ppm CO_2-eq) respectively. Dark bars denote reductions for a target of 650ppm CO_2-eq and light bars denote the additional reductions to achieve 490 to 540ppm CO_2-eq. Note that some models do not consider mitigation through forest sink enhancement (AIM and IPAC) or CCS (AIM) and that the share of low-carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. CCS includes CO_2 capture and storage from biomass. Forest sinks include reducing emissions from deforestation. The figure shows emissions reductions from baseline scenarios with cumulative emissions between 6000 to 7000 $GtCO_2$-eq (2000-2100). {WGIII Figure SPM.9}*

[32] By comparison, government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level. {WGIII 2.7, 3.4, 4.5, 11.5, 13.2}

5.6 Costs of mitigation and long-term stabilisation targets

The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target and are relatively higher when derived from baseline scenarios characterised by high emission levels. ***{WGIII SPM}***

There is *high agreement* and *medium evidence* that in 2050 global average macro-economic costs for multi-gas mitigation towards stabilisation between 710 and 445ppm CO_2-eq are between a 1% gain to a 5.5% decrease of global GDP (Table 5.2). This corresponds to slowing average annual global GDP growth by less than 0.12 percentage points. Estimated GDP losses by 2030 are on average lower and show a smaller spread compared to 2050 (Table 5.2). For specific countries and sectors, costs vary considerably from the global average.[33] *{WGIII 3.3, 13.3, SPM}*

5.7 Costs, benefits and avoided climate impacts at global and regional levels

Impacts of climate change will vary regionally. Aggregated and discounted to the present, they are *very likely* to impose net annual costs, which will increase over time as global temperatures increase. ***{WGII SPM}***

For increases in global average temperature of less than 1 to 3°C above 1980-1999 levels, some impacts are projected to produce market benefits in some places and sectors while, at the same time, imposing costs in other places and sectors. Global mean losses could be 1 to 5% of GDP for 4°C of warming, but regional losses could be substantially higher. *{WGII 9.ES, 10.6, 15.ES, 20.6, SPM}*

Peer-reviewed estimates of the social cost of carbon (net economic costs of damages from climate change aggregated across the globe and discounted to the present) for 2005 have an average value of US$12 per tonne of CO_2, but the range from 100 estimates is large (-$3 to $95/t$CO_2$). The range of published evidence indicates that the net damage costs of climate change are projected to be significant and to increase over time. *{WGII 20.6, SPM}*

It is *very likely* that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. It is *virtually certain* that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations. In some locations and amongst some groups of people with high exposure, high sensitivity and/or low adaptive capacity, net costs will be significantly larger than the global average. *{WGII 7.4, 20.ES, 20.6, 20.ES, SPM}*

Limited and early analytical results from integrated analyses of the global costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs. ***{WGIII SPM}***

Comparing the costs of mitigation with avoided damages would require the reconciliation of welfare impacts on people living in different places and at different points in time into a global aggregate measure of well-being. *{WGII 18.ES}*

Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay. *{WGIII SPM}*

Many impacts can be avoided, reduced or delayed by mitigation. ***{WGII SPM}***

Although the small number of impact assessments that evaluate stabilisation scenarios do not take full account of uncertainties in projected climate under stabilisation, they nevertheless provide indications of damages avoided and risks reduced for different

Table 5.2. *Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {WGIII 3.3, 13.3, Tables SPM.4 and SPM.6}*

Stabilisation levels (ppm CO_2-eq)	Median GDP reduction[a] (%)		Range of GDP reduction[b] (%)		Reduction of average annual GDP growth rates (percentage points)[c,e]	
	2030	2050	2030	2050	2030	2050
445 – 535[d]	Not available		<3	<5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

Notes:
Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.
a) Global GDP based on market exchange rates.
b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535ppm CO_2-eq) gives the upper bound estimate of the literature only.
c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.
d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.
e) The values correspond to the highest estimate for GDP reduction shown in column three.

[33] See Footnote 24 for further details on cost estimates and model assumptions.

amounts of emissions reduction. The rate and magnitude of future human-induced climate change and its associated impacts are determined by human choices defining alternative socio-economic futures and mitigation actions that influence emission pathways. Figure 3.2 demonstrates that alternative SRES emission pathways could lead to substantial differences in climate change throughout the 21st century. Some of the impacts at the high temperature end of Figure 3.6 could be avoided by socio-economic development pathways that limit emissions and associated climate change towards the lower end of the ranges illustrated in Figure 3.6. *{SYR 3.2, 3.3; WGIII 3.5, 3.6, SPM}*

Figure 3.6 illustrates how reduced warming could reduce the risk of, for example, affecting a significant number of ecosystems, the risk of extinctions, and the likelihood that cereal productivity in some regions would tend to fall. *{SYR 3.3, Figure 3.6; WGII 4.4, 5.4, Table 20.6}*

5.8 Broader environmental and sustainability issues

Sustainable development can reduce vulnerability to climate change, and climate change could impede nations' abilities to achieve sustainable development pathways. ***{WGII SPM}***

It is *very likely* that climate change can slow the pace of progress toward sustainable development either directly through increased exposure to adverse impacts or indirectly through erosion of the capacity to adapt. Over the next half-century, climate change could impede achievement of the Millennium Development Goals. *{WGII SPM}*

Climate change will interact at all scales with other trends in global environmental and natural resource concerns, including water, soil and air pollution, health hazards, disaster risk, and deforestation. Their combined impacts may be compounded in future in the absence of integrated mitigation and adaptation measures. *{WGII 20.3, 20.7, 20.8, SPM}*

Making development more sustainable can enhance mitigative and adaptive capacities, reduce emissions, and reduce vulnerability, but there may be barriers to implementation. ***{WGII 20.8; WGIII 12.2, SPM}***

Both adaptive and mitigative capacities can be enhanced through sustainable development. Sustainable development can, thereby, reduce vulnerability to climate change by reducing sensitivities (through adaptation) and/or exposure (through mitigation). At present, however, few plans for promoting sustainability have explicitly included either adapting to climate change impacts, or promoting adaptive capacity. Similarly, changing development paths can make a major contribution to mitigation but may require resources to overcome multiple barriers. *{WGII 20.3, 20.5, SPM; WGIII 2.1, 2.5, 12.1, SPM}*

6

Robust findings, key uncertainties

Robust findings, key uncertainties

As in the TAR, a robust finding for climate change is defined as one that holds under a variety of approaches, methods, models and assumptions, and is expected to be relatively unaffected by uncertainties. Key uncertainties are those that, if reduced, could lead to new robust findings. *{TAR SYR Q.9}*

Robust findings do not encompass all key findings of the AR4. Some key findings may be policy-relevant even though they are associated with large uncertainties. *{WGII 20.9}*

The robust findings and key uncertainties listed below do not represent an exhaustive list.

6.1 Observed changes in climate and their effects, and their causes

Robust findings

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. *{WGI 3.9, SPM}*

Many natural systems, on all continents and in some oceans, are being affected by regional climate changes. Observed changes in many physical and biological systems are consistent with warming. As a result of the uptake of anthropogenic CO_2 since 1750, the acidity of the surface ocean has increased. *{WGI 5.4, WGII 1.3}*

Global total annual anthropogenic GHG emissions, weighted by their 100-year GWPs, have grown by 70% between 1970 and 2004. As a result of anthropogenic emissions, atmospheric concentrations of N_2O now far exceed pre-industrial values spanning many thousands of years, and those of CH_4 and CO_2 now far exceed the natural range over the last 650,000 years. *{WGI SPM; WGIII 1.3}*

Most of the global average warming over the past 50 years is *very likely* due to anthropogenic GHG increases and it is *likely* that there is a discernible human-induced warming averaged over each continent (except Antarctica). *{WGI 9.4, SPM}*

Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems. *{WGII 1.4, SPM}*

Key uncertainties

Climate data coverage remains limited in some regions and there is a notable lack of geographic balance in data and literature on observed changes in natural and managed systems, with marked scarcity in developing countries. *{WGI SPM; WGII 1.3, SPM}*

Analysing and monitoring changes in extreme events, including drought, tropical cyclones, extreme temperatures and the frequency and intensity of precipitation, is more difficult than for climatic averages as longer data time-series of higher spatial and temporal resolutions are required. *{WGI 3.8, SPM}*

Effects of climate changes on human and some natural systems are difficult to detect due to adaptation and non-climatic drivers. *{WGII 1.3}*

Difficulties remain in reliably simulating and attributing observed temperature changes to natural or human causes at smaller than continental scales. At these smaller scales, factors such as land-use change and pollution also complicate the detection of anthropogenic warming influence on physical and biological systems. *{WGI 8.3, 9.4, SPM; WGII 1.4, SPM}*

The magnitude of CO_2 emissions from land-use change and CH_4 emissions from individual sources remain as key uncertainties. *{WGI 2.3, 7.3, 7.4; WGIII 1.3, TS.14}*

6.2 Drivers and projections of future climate changes and their impacts

Robust findings

With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. *{WGIII 3.2, SPM}*

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. *{WGI 10.3, 10.7, SPM}*

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. *{WGI 10.3, 11.1, SPM}*

The pattern of future warming where land warms more than the adjacent oceans and more in northern high latitudes is seen in all scenarios. *{WGI 10.3, 11.1, SPM}*

Warming tends to reduce terrestrial ecosystem and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions that remains in the atmosphere. *{WGI 7.3, 10.4, 10.5, SPM}*

Anthropogenic warming and sea level rise would continue for centuries even if GHG emissions were to be reduced sufficiently for GHG concentrations to stabilise, due to the time scales associated with climate processes and feedbacks. *{WGI 10.7, SPM}*

Equilibrium climate sensitivity is *very unlikely* to be less than 1.5°C. *{WGI 8.6, 9.6, Box 10.2, SPM}*

Some systems, sectors and regions are *likely* to be especially affected by climate change. The systems and sectors are some ecosystems (tundra, boreal forest, mountain, mediterranean-type, mangroves, salt marshes, coral reefs and the sea-ice biome), low-lying coasts, water resources in some dry regions at mid-latitudes and in the dry topics and in areas dependent on snow and ice melt, agriculture in low-latitude regions, and human health in areas with low adaptive capacity. The regions are the Arctic, Africa, small islands and Asian and African megadeltas. Within other regions, even those with high incomes, some people, areas and activities can be particularly at risk. *{WGII TS.4.5}*

Impacts are *very likely* to increase due to increased frequencies and intensities of some extreme weather events. Recent events have demonstrated the vulnerability of some sectors and regions, including in developed countries, to heat waves, tropical cyclones, floods and drought, providing stronger reasons for concern as compared to the findings of the TAR. *{WGII Table SPM.2, 19.3}*

Key uncertainties

Uncertainty in the equilibrium climate sensitivity creates uncertainty in the expected warming for a given CO_2-eq stabilisation scenario. Uncertainty in the carbon cycle feedback creates uncertainty in the emissions trajectory required to achieve a particular stabilisation level. *{WGI 7.3, 10.4, 10.5, SPM}*

Models differ considerably in their estimates of the strength of different feedbacks in the climate system, particularly cloud feedbacks, oceanic heat uptake and carbon cycle feedbacks, although progress has been made in these areas. Also, the confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation), and it is higher for larger spatial scales and longer time averaging periods. *{WGI 7.3, 8.1-8.7, 9.6, 10.2, 10.7, SPM; WGII 4.4}*

Aerosol impacts on the magnitude of the temperature response, on clouds and on precipitation remain uncertain. *{WGI 2.9, 7.5, 9.2, 9.4, 9.5}*

Future changes in the Greenland and Antarctic ice sheet mass, particularly due to changes in ice flow, are a major source of uncertainty that could increase sea level rise projections. The uncertainty in the penetration of the heat into the oceans also contributes to the future sea level rise uncertainty. *{WGI 4.6, 6.4, 10.3, 10.7, SPM}*

Large-scale ocean circulation changes beyond the 21st century cannot be reliably assessed because of uncertainties in the meltwater supply from the Greenland ice sheet and model response to the warming. *{WGI 6.4, 8.7, 10.3 }*

Projections of climate change and its impacts beyond about 2050 are strongly scenario- and model-dependent, and improved projections would require improved understanding of sources of uncertainty and enhancements in systematic observation networks. *{WGII TS.6}*

Impacts research is hampered by uncertainties surrounding regional projections of climate change, particularly precipitation. *{WGII TS.6}*

Understanding of low-probability/high-impact events and the cumulative impacts of sequences of smaller events, which is required for risk-based approaches to decision-making, is generally limited. *{WGII 19.4, 20.2, 20.4, 20.9, TS.6}*

6.3 Responses to climate change

Robust findings

Some planned adaptation (of human activities) is occurring now; more extensive adaptation is required to reduce vulnerability to climate change. *{WGII 17.ES, 20.5, Table 20.6, SPM}*

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. *{WGII 20.7, SPM}*

A wide range of mitigation options is currently available or projected to be available by 2030 in all sectors. The economic mitigation potential, at costs that range from net negative up to US$100/ tCO_2-equivalent, is sufficient to offset the projected growth of global emissions or to reduce emissions to below current levels in 2030. *{WGIII 11.3, SPM}*

Many impacts can be reduced, delayed or avoided by mitigation. Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels. Delayed emissions reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. *{WGII SPM, WGIII SPM}*

The range of stabilisation levels for GHG concentrations that have been assessed can be achieved by deployment of a portfolio of technologies that are currently available and those that are expected to be commercialised in coming decades, provided that appropriate and effective incentives are in place and barriers are removed. In addition, further RD&D would be required to improve the technical performance, reduce the costs and achieve social acceptability of new technologies. The lower the stabilisation levels, the greater the need for investment in new technologies during the next few decades. *{WGIII 3.3, 3.4}*

Making development more sustainable by changing development paths can make a major contribution to climate change mitigation and adaptation and to reducing vulnerability. *{WGII 18.7, 20.3, SPM; WGIII 13.2, SPM}*

Decisions about macro-economic and other policies that seem unrelated to climate change can significantly affect emissions. *{WGIII 12.2}*

Key uncertainties

Understanding of how development planners incorporate information about climate variability and change into their decisions is limited. This limits the integrated assessment of vulnerability. *{WGII 18.8, 20.9}*

The evolution and utilisation of adaptive and mitigative capacity depend on underlying socio-economic development pathways. *{WGII 17.3, 17.4, 18.6, 19.4, 20.9}*

Barriers, limits and costs of adaptation are not fully understood, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints. *{WGII SPM}*

Estimates of mitigation costs and potentials depend on assumptions about future socio-economic growth, technological change and consumption patterns. Uncertainty arises in particular from assumptions regarding the drivers of technology diffusion and the potential of long-term technology performance and cost improvements. Also little is known about the effects of changes in behaviour and lifestyles. *{WGIII 3.3, 3.4, 11.3}*

The effects of non-climate policies on emissions are poorly quantified. *{WGIII 12.2}*

EXHIBIT H

CLIMATE CHANGE SCIENCE

AN ANALYSIS OF SOME KEY QUESTIONS

Committee on the Science of Climate Change

Division on Earth and Life Studies

National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C.

3

Human Caused Forcings

Are concentrations of greenhouse gases and other emissions that contribute to climate change increasing at an accelerating rate, and are different greenhouse gases and other emissions increasing at different rates?

Is human activity the cause of increased concentrations of greenhouse gases and other emissions that contribute to climate change?

What other emissions are contributing factors to climate change (e.g., aerosols, CO, black carbon soot), and what is their relative contribution to climate change?

How long does it take to reduce the buildup of greenhouse gases and other emissions that contribute to climate change?

Do different greenhouse gases and other emissions have different draw down periods?

Are greenhouse gases causing climate change?

GREENHOUSE GASES

The most important greenhouse gases in Earth's atmosphere include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor (H_2O), ozone (O_3), and the chlorofluorocarbons (CFCs including CFC-12 (CCl_2F_2) and CFC-11 (CCl_3F)). In addition to reflecting sunlight, clouds are also a major greenhouse substance. Water vapor and cloud droplets are in fact the dominant atmospheric absorbers, and how these substances respond to climate forcings is a principal determinant of climate sensitivity, as discussed in Section 1. The CO_2, CH_4, N_2O and H_2O are both produced and utilized in many biological processes, although the major source of gaseous water is evaporation from the oceans. Ozone is created in the atmosphere by reactions initiated by sunlight. The CFCs are synthetic compounds developed and released into the atmosphere by humankind. In addition, sulfur hexafluoride (SF_6) and perfluorocarbon gases such as carbon tetrafluoride (CF_4) are very potent and nearly inert greenhouse gases with atmospheric lifetimes much longer than 1000 years.

The natural atmosphere contained many greenhouse gases whose atmospheric concentrations were determined by the sum of the ongoing geophysical, biological, and chemical reactions that produce and destroy them. The specific effects of humankind's activities before the industrial era were immersed in all of the natural dynamics and became noticeable only in the immediate vicinity, as with the smoke from small fires. The theoretical realization that human activities could have a global discernible effect on the atmosphere came during the 19th century, and the first conclusive measurements of atmospheric change were made during the last half of the 20th century. The first greenhouse gas demonstrated to be increasing in atmospheric concentration was carbon dioxide, formed as a major end product in the extraction of energy from the burning of the fossil fuels—coal, oil, and natural gas—as well as in the burning of biomass.

The common characteristics of greenhouse gases are (1) an ability to absorb terrestrial infrared radiation and (2) a presence in Earth's atmosphere. The most important greenhouse gases listed above all contain three or more atoms per molecule. Literally thousands of gases have been identified as being present in the atmosphere at some place and at some time, and all but a few have the ability to absorb terrestrial infrared radiation. However, the great majority of these

chemical compounds, both natural[1] and anthropogenic, are removed in hours, days, or weeks, and do not accumulate in significant concentrations. Some can have an indirect greenhouse effect, as with carbon monoxide (CO).[2] If the average survival time for a gas in the atmosphere is a year or longer, then the winds have time to spread it throughout the lower atmosphere, and its absorption of terrestrial infrared radiation occurs at all latitudes and longitudes. All the listed greenhouse gases except ozone are released to the atmosphere at Earth's surface and are spread globally throughout the lower atmosphere.

The lifetime of CH_4 in the atmosphere is 10-12 years. Nitrous oxide and the CFCs have century-long lifetimes before they are destroyed in the stratosphere. Atmospheric CO_2 is not destroyed chemically, and its removal from the atmosphere takes place through multiple processes that transiently store the carbon in the land and ocean reservoirs, and ultimately as mineral deposits. A major removal process depends on the transfer of the carbon content of near-surface waters to the deep ocean, which has a century time scale, but final removal stretches out over hundreds of thousands of years. Reductions in the atmospheric concentrations of these gases following possible lowered emission rates in the future will stretch out over decades for methane, and centuries and longer for carbon dioxide and nitrous oxide.

Methane, nitrous oxide, and ozone all have natural sources, but they can also be introduced into the atmosphere by the activities of humankind. These supplementary sources have contributed to the increasing concentrations of these gases during the 20th century.

Carbon Dioxide

While all of the major greenhouse gases have both natural and anthropogenic atmospheric sources, the nature of these processes varies widely among them. Carbon dioxide is naturally absorbed and released by the terrestrial biosphere as well as by the oceans. Carbon dioxide is also formed by the burning of wood, coal, oil, and natural gas, and these activities have increased steadily during the last two centuries since the Industrial Revolution. That the burning of fossil fuels is a major cause of the CO_2 increase is evidenced by the concomitant decreases in the relative abundance of both the stable and radioactive carbon isotopes[3] and the decrease in atmospheric oxygen. Continuous high-precision measurements have been made of its atmospheric concentrations only since 1958, and by the year 2000 the concentrations had increased 17% from 315 parts per million by volume (ppmv) to 370 ppmv. While the year-to-year increase varies, the average annual increase of 1.5 ppmv/year over the past two decades is slightly greater than during the 1960s and 1970s. A marked seasonal oscillation of carbon dioxide concentration exists, especially in the northern hemisphere because of the extensive draw down of carbon dioxide every spring and summer as the green plants convert carbon dioxide into plant material, and the return in the rest of the year as decomposition exceeds photosynthesis. The seasonal effects are quite different north and south of the equator, with the variation much greater in the northern hemisphere where most of Earth's land surface and its vegetation and soils are found.

The atmospheric CO_2 increase over the past few decades is less than the input from human activities because a fraction of the added CO_2 is removed by oceanic and terrestrial processes. Until recently, the partitioning of the carbon sink between the land and sea has been highly uncertain, but recent high-precision measurements of the atmospheric oxygen:nitrogen (O_2:N_2) ratio have provided a crucial constraint: fossil fuel burning and terrestrial uptake processes have different O_2:CO_2 ratios, whereas the ocean CO_2 sink has no significant impact on atmospheric O_2. The atmospheric CO_2 increase for the 1990s was about half the CO_2 emission from fossil fuel combustion, with the oceans and land both serving as important repositories of the excess carbon, i.e., as carbon sinks.

Land gains and loses carbon by various processes: some natural-like photosynthesis and decomposition, some connected to land use and land management practices, and some responding to the increases of carbon dioxide or other nutrients necessary for plant growth. These gains or losses dominate the net land exchange of carbon dioxide with the atmosphere, but some riverine loss to oceans is also significant. Most quantifiable, as by forest and soil inventories, are the above- and below-ground carbon losses from land clearing and the gains in storage in trees from forest recovery and management. Changes in the frequency of forest fires, such as from fire suppression policies, and agricultural practices for soil conservation may modify the carbon stored by land. Climate variations, through their effects on plant growth and decomposition of soil detritus, also have large effects on terrestrial carbon fluxes and storage on a year-to-year basis. Land modifications, mainly in the middle latitudes of the northern hemisphere, may have been a net source of carbon dioxide to the atmosphere over much of the last century. However, quantitative estimates have only been possible over the last two decades, when forest clearing had shifted to the tropics. In the 1980s land became a small net sink for

[1]While the activities of mankind are part of the natural world, the convention exists in most discussions of the atmosphere that "natural processes" are those that would still exist without the presence of human beings; those processes that are significantly influenced by humans are called "anthropogenic".

[2]Both carbon monoxide and methane are removed from the atmosphere by chemical reaction with hydroxyl (OH). An increase in the carbon monoxide uses up hydroxyl, slowing methane removal and allowing its concentration and greenhouse effect to increase.

[3]Fossil fuels are of biological origin and are depleted in both the stable isotope ^{13}C and the radioactive isotope ^{14}C, which has a half-life of 5600 years.

carbon, that is, the various processes storing carbon globally exceeded the loss due to tropical deforestation, which by itself was estimated to add 10-40% as much carbon dioxide to the atmosphere as burning of fossil fuels. In the 1990s the net storage on land became much larger, nearly as large as the ocean uptake. How land contributes, by location and processes, to exchanges of carbon with the atmosphere is still highly uncertain, as is the possibility that the substantial net removal will continue to occur very far into the future.[4]

Methane

Methane is the major component of natural gas and it is also formed and released to the atmosphere by many biologic processes in low oxygen environments, such as those occurring in swamps, near the roots of rice plants, and the stomachs of cows. Such human activities as rice growing, the raising of cattle, coal mining, use of land-fills, and natural-gas handling have increased over the last 50 years, and direct and inadvertent emissions from these activities have been partially responsible for the increase in atmospheric methane. Its atmospheric concentration has been measured globally and continuously for only two decades, and the majority of the methane molecules are of recent biologic origin. The concentrations of methane increased rather smoothly from 1.52 ppmv in 1978 by about 1% per year until about 1990. The rate of increase slowed down to less than that rate during the 1990s, and also became more erratic; current values are around 1.77 ppmv. About two-thirds of the current emissions of methane are released by human activities. There is no definitive scientific basis for choosing among several possible explanations for these variations in the rates of change of global methane concentrations, making it very difficult to predict its future atmospheric concentrations.

Both carbon dioxide and methane were trapped long ago in air bubbles preserved in Greenland and Antarctic ice sheets. These ice sheets are surviving relics of the series of ice ages that Earth experienced over the past 400,000 years. Concentrations of carbon dioxide extracted from ice cores have typically ranged between 190 ppmv during the ice ages to near 280 ppmv during the warmer "interglacial" periods like the present one that began around 10,000 years ago. Concentrations did not rise much above 280 ppmv until the Industrial Revolution. The methane concentrations have also varied during this 400,000 year period, with lowest values of 0.30 ppmv in the coldest times of the ice ages and 0.70 ppmv in the warmest, until a steady rise began about 200 years ago toward the present concentrations. Both carbon dioxide and methane are more abundant in Earth's atmosphere now than at any time during the past 400,000 years.

Other Greenhouse Gases

Nitrous oxide is formed by many microbial reactions in soils and waters, including those processes acting on the increasing amounts of nitrogen-containing fertilizers. Some synthetic chemical processes that release nitrous oxide have also been identified. Its concentration remained about 0.27 ppmv for at least 1,000 years until two centuries ago, when the rise to the current 0.31 ppmv began.

Ozone is created mainly by the action of solar ultraviolet radiation on molecular oxygen in the upper atmosphere, and most of it remains in the stratosphere. However, a fraction of such ozone descends naturally into the lower atmosphere where additional chemical processes can both form and destroy it. This "tropospheric ozone" has been supplemented during the 20th century by additional ozone—an important component of photochemical smog—created by the action of sunlight upon pollutant molecules containing carbon and nitrogen. The most important of the latter include compounds such as ethylene (C_2H_4), carbon monoxide (CO), and nitric oxide released in the exhaust of fossil-fuel-powered motor vehicles and power plants and during combustion of biomass. The lifetime of ozone is short enough that the molecules do not mix throughout the lower atmosphere, but instead are found in broad plumes downwind from the cities of origin, which merge into regional effects, and into a latitude band of relatively high ozone extending from 30°N to 50°N that encircles Earth during Northern Hemisphere spring and summer. The presence of shorter-lived molecules, such as ozone, in the troposphere depends upon a steady supply of newly formed molecules, such as those created daily by traffic in the large cities of the world. The widespread practice of clearing forests and agricultural wastes ("biomass burning"), especially noticeable in the tropics and the Southern Hemisphere, contributes to tropospheric ozone.

The chlorofluorocarbons (CFCs) are different from the gases considered above in that they have no significant natural source but were synthesized for their technological utility. Essentially all of the major uses of the CFCs—as refrigerants, aerosol propellants, plastic foaming agents, cleaning solvents, and so on—result in their release, chemically unaltered, into the atmosphere. The atmospheric concentrations of the CFCs rose, slowly at first, from zero before first synthesis in 1928, and then more rapidly in the 1960s and 1970s with the development of a widening range of technological applications. The concentrations were rising in the 1980s at a rate of about 18 parts per trillion by volume (pptv) per year for CFC-12, 9 pptv/year for CFC-11, and 6 pptv/year for CFC-113 (CCl_2FCClF_2). Because these molecules were

[4] The variations and uncertainties in the land carbon balance are important not only in the contemporary carbon budget. While the terrestrial carbon reservoirs are small compared to the oceans, the possibility of destabilizing land ecosystems and releasing the stored carbon, e.g. from the tundra soils, has been hypothesized.

identified as agents causing the destruction of stratospheric ozone,[5] their production was banned in the industrial countries as of January 1996 under the terms of the 1992 revision of the Montreal Protocol, and further emissions have almost stopped. The atmospheric concentrations of CFC-11 and CFC-113 are now slowly decreasing, and that of CFC-12 has been essentially level for the past several years. However, because of the century-long lifetimes of these CFC molecules, appreciable atmospheric concentrations of each will survive well into the 22nd century.

Many other fluorinated compounds (such as carbon tetrafluoride, CF_4, and sulfur hexafluoride, SF_6), also have technological utility, and significant greenhouse gas capabilities. Their very long atmospheric lifetimes are a source of concern even though their atmospheric concentrations have not yet produced large radiative forcings. Members of the class of compounds called hydrofluorocarbons (HFCs) also have a greenhouse effect from the fluorine, but the hydrogen in the molecule allows reaction in the troposphere, reducing both its atmospheric lifetime and the possible greenhouse effect. The atmospheric concentrations of all these gases, which to date are only very minor greenhouse contributors, need to be continuously monitored to ensure that no major sources have developed. The sensitivity and generality of modern analytic systems make it unlikely that any additional greenhouse gas will be discovered that is already a significant contributor to the current total greenhouse effect.

AEROSOLS

Sulfate and carbon-bearing compounds associated with particles (i.e., carbonaceous aerosols) are two classes of aerosols that impact radiative balances, and therefore influence climate.

Black Carbon (soot)

The study of the role of black carbon in the atmosphere is relatively new. As a result it is characterized poorly as to its composition, emission source strengths, and influence on radiation. Black carbon is an end product of the incomplete combustion of fossil fuels and biomass, the latter resulting from both natural and human-influenced processes. Most of the black carbon is associated with fine particles (radius <0.2 μm) that have global residence times of about one week. These lifetimes are considerably shorter than those of most greenhouse gases, and thus the spatial distribution of black carbon aerosol is highly variable, with the greatest concentrations near the production regions. Because of the scientific uncertainties associated with the sources and composition of carbonaceous aerosols, projections of future impacts on climate are difficult. However, the increased burning of fossil fuels and the increased burning of biomass for land clearing may result in increased black carbon concentration globally.

Sulfate

The precursor to sulfate is sulfur dioxide gas, which has two primary natural sources: emissions from marine biota and volcanic emissions. During periods of low volcanic activity, the primary source of sulfur dioxide in regions downwind from continents is the combustion of sulfur-rich coals; less is contributed by other fossil fuels. In oceanic regions far removed from continental regions, the biologic source should dominate. However, model analyses, accounting for the ubiquitous presence of ships, indicate that even in these remote regions combustion is a major source of the sulfur dioxide. Some of the sulfur dioxide attaches to sea-salt aerosol where it is oxidized to sulfate. The sea salt has a residence time in the atmosphere on the order of hours to days, and it is transported in the lower troposphere. Most sulfate aerosol is associated with small aerosols (radius <1 μm) and is transported in the upper troposphere with an atmospheric lifetime on the order of one week. Recent "clean coal technologies" and the use of low sulfur fossil fuels have resulted in decreasing sulfate concentrations, especially in North America and regions downwind. Future atmospheric concentrations of sulfate aerosols will be determined by the extent of non-clean coal burning techniques, especially in developing nations.

CLIMATE FORCINGS IN THE INDUSTRIAL ERA

Figure 1 summarizes climate forcings that have been introduced during the period of industrial development, between 1750 and 2000, as estimated by the IPCC. Some of these forcings, mainly greenhouse gases, are known quite accurately, while others are poorly measured. A range of uncertainty has been estimated for each forcing, represented by an uncertainty bar or "whisker." However, these estimates are partly subjective, and it is possible that the true forcing falls outside the indicated range in some cases.

Greenhouse Gases

Carbon dioxide (CO_2) is probably the most important climate forcing agent today, causing an increased forcing of about 1.4 W/m^2. CO_2 climate forcing is likely to become more dominant in the future as fossil fuel use continues. If fossil fuels continue to be used at the current rate, the added

[5]Eighty-five percent of the mass of the atmosphere lies in the troposphere, the region between the surface and an altitude of about 10 miles. About 90% of Earth's ozone is found in the stratosphere, and the rest is in the troposphere.

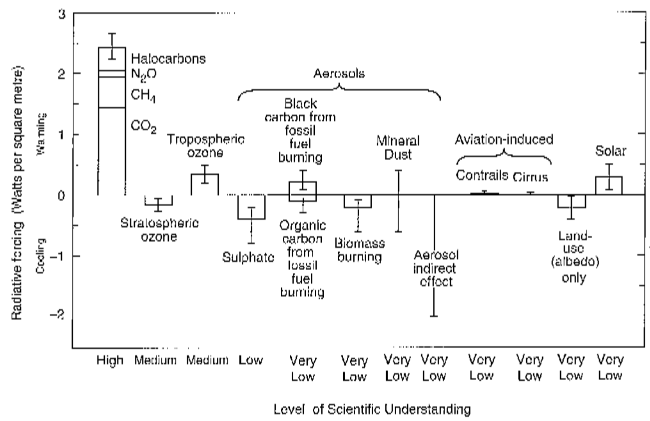


FIGURE 1 The global mean radiative forcing of the climate system for the year 2000, relative to 1750, and the associated confidence levels with which they are known. (From IPCC, 2001; reprinted with permission of the Intergovernmental Panel on Climate Change.)

CO_2 forcing in 50 years will be about 1 W/m^2. If fossil fuel use increases by 1-1.5% per year for 50 years, the added CO_2 forcing instead will be about 2 W/m^2. These estimates account for the non-linearity caused by partial saturation in some greenhouse gas infrared absorption bands, yet they are only approximate because of uncertainty about how efficiently the ocean and terrestrial biosphere will sequester atmospheric CO_2. The estimates also presume that during the next 50 years humans will not, on a large scale, capture and sequester the CO_2 released during fossil-fuel burning.

Other greenhouse gases together cause a climate forcing approximately equal to that of CO_2. Any increase in CH_4 also indirectly causes further climate forcing by increasing stratospheric H_2O (about 7% of the CH_4 is oxidized in the upper atmosphere), as well as by increasing tropospheric O_3 through reactions involving OH and nitrogen oxides. The total climate forcing by CH_4 is at least a third as large as the CO_2 forcing, and it could be half as large as the CO_2 forcing when the indirect effects are included.

Methane is an example of a forcing whose growth could be slowed or even stopped entirely or reversed. The common scenarios for future climate change assume that methane will continue to increase. If instead its amount were to remain constant or decrease, the net climate forcing could be significantly reduced. The growth rate of atmospheric methane has slowed by more than half in the past two decades for reasons that are not well understood. With a better understanding of the sources and sinks of methane, it may be possible to encourage practices (for example, reduced leakage during fossil-fuel mining and transport, capture of land-fill emissions, and more efficient agricultural practices) that lead to a decrease in atmospheric methane and significantly reduce future climate change. The atmospheric lifetime of methane is of the order of a decade, therefore, unlike CO_2, emission changes will be reflected in changed forcing rather quickly.

Tropospheric ozone (ozone in the lower 5-10 miles of the atmosphere) has been estimated to cause a climate forcing of about 0.4 W/m^2. Some of this is linked to methane increases as discussed above, and attribution of the ozone forcing between chemical factors such as methane, carbon monoxide, and other factors is a challenging problem. One recent study, based in part on limited observations of ozone in the late 1800s, suggested that human-made ozone forcing could be as large as about 0.7-0.8 W/m^2. Surface level ozone is a major ingredient in air pollution with substantial impacts on human health and agricultural productivity. The potential human and economic gains from reduced ozone pollution and its importance as a climate forcing make it an attractive target for further study as well as possible actions that could lead to reduced ozone amounts or at least a halt in its further growth.

Aerosols

Climate forcing by anthropogenic aerosols is a large source of uncertainty about future climate change. On the basis of estimates of past climate forcings, it seems likely that aerosols, on a global average, have caused a negative climate forcing (cooling) that has tended to offset much of the positive forcing by greenhouse gases. Even though aerosol distributions tend to be regional in scale, the forced climate response is expected to occur on larger, even hemispheric and global, scales. The monitoring of aerosol properties has not been adequate to yield accurate knowledge of the aerosol climate influence.

Estimates of the current forcing by sulfates fall mainly in the range –0.3 to –1 W/m^2. However, the smaller values do not fully account for the fact that sulfate aerosols swell in size substantially in regions of high humidity. Thus, the sulfate forcing probably falls in the range –0.6 to –1 W/m^2. Further growth of sulfate aerosols is likely to be limited by concerns about their detrimental effects, especially acid rain, and it is possible that control of sulfur emissions from combustion will even cause the sulfate amount to decrease.

Black carbon (soot) aerosols absorb sunlight and, even though this can cause a local cooling of the surface in regions of heavy aerosol concentration, it warms the atmosphere and, for plausible atmospheric loadings, soot is expected to cause a global surface warming. IPCC reports have provided a best estimate for the soot forcing of 0.1-0.2 W/m^2, but with large uncertainty. One recent study that accounts for the larger absorption that soot can cause when it is mixed internally with other aerosols suggests that its direct forcing

is at least 0.4 W/m^2. It also has been suggested that the indirect effects of black carbon—which include reducing low-level cloud cover (by heating of the layer), making clouds slightly "dirty" (darker), and lowering of the albedo of snow and sea ice—might double this forcing to 0.8 W/m^2. The conclusion is that the black carbon aerosol forcing is uncertain but may be substantial. Thus there is the possibility that decreasing black carbon emissions in the future could have a cooling effect that would at least partially compensate for the warming that might be caused by a decrease in sulfates.

Other aerosols are also significant. Organic carbon aerosols are produced naturally by vegetation and anthropogenically in the burning of fossil fuels and biomass. Organic carbon aerosols thus accompany and tend to be absorbed by soot aerosols, and they are believed to increase the toxicity of the aerosol mixture. It is expected that efforts to reduce emissions of black carbon would also reduce organic carbon emissions. Ammonium nitrate (not included in Figure 1) recently has been estimated to cause a forcing of –0.2 W/m^2.

Mineral dust, along with sea salt, sulfates, and organic aerosols, contributes a large fraction of the global aerosol mass. It is likely that human land-use activities have influenced the amount of mineral dust in the air, but trends are not well measured. Except for iron-rich soil, most mineral dust probably has a cooling effect, but this has not been determined well.

The greatest uncertainty about the aerosol climate forcing—indeed, the largest of all the uncertainties about global climate forcings—is probably the indirect effect of aerosols on clouds. Aerosols serve as condensation nuclei for cloud droplets. Thus, anthropogenic aerosols are believed to have two major effects on cloud properties: the increased number of nuclei results in a larger number of smaller cloud droplets, thus increasing the cloud brightness (the Twomey effect), and the smaller droplets tends to inhibit rainfall, thus increasing cloud lifetime and the average cloud cover on Earth. Both effects reduce the amount of sunlight absorbed by Earth and thus tend to cause global cooling. The existence of these effects has been verified in field studies, but it is extremely difficult to determine their global significance. Climate models that incorporate the aerosol-cloud physics suggest that these effects may produce a negative global forcing on the order of 1 W/m^2 or larger. The great uncertainty about this indirect aerosol climate forcing presents a severe handicap both for the interpretation of past climate change and for future assessments of climate changes.

Other Forcings

Other potentially important climate forcings include volcanic aerosols, anthropogenic land use, and solar variability. Stratospheric aerosols produced by large volcanoes that eject gas and dust to altitudes of 12 miles or higher can cause a climate forcing as large as several watts per square meter on global average. However, the aerosols fall out after a year or two, so unless there is an unusual series of eruptions, they do not contribute to long-term climate change.

Land-use changes, especially the removal or growth of vegetation, can cause substantial regional climate forcing. One effect that has been evaluated in global climate models is the influence of deforestation. Because forests are dark and tend to mask underlying snow, the replacement of forests by crops or grass yields a higher albedo surface and thus a cooling effect. This effect has been estimated to yield a global cooling tendency in the industrial era equivalent to a forcing of –0.2 W/m^2. Land use changes have been an important contributor to past changes of atmospheric carbon dioxide. However, the impacts of such changes on climate may be much more significant on regional scales than globally, and largely act through changes of the hydrologic cycle. Such impacts are currently poorly characterized because they depend on complex modeling details that are still actively being improved.

Solar irradiance, the amount of solar energy striking Earth, has been monitored accurately only since the late 1970s. However, indirect measures of solar activity suggest that there has been a positive trend of solar irradiance over the industrial era, providing a forcing estimated at about 0.3 W/m^2. Numerous possible indirect forcings associated with solar variability have been suggested. However, only one of these, ozone changes induced by solar ultraviolet irradiance variations, has convincing observational support. Some studies have estimated this indirect effect to enhance the direct solar forcing by 0.1 W/m^2, but this value remains highly uncertain. Although the net solar forcing appears small in comparison with the sum of all greenhouse gases, it is perhaps more appropriate to compare the solar forcing with the net anthropogenic forcing. Solar forcing is very uncertain, but almost certainly much smaller than the greenhouse gas forcing. It is not implausible that solar irradiance has been a significant driver of climate during part of the industrial era, as suggested by several modeling studies. However, solar forcing has been measured to be very small since 1980, and greenhouse gas forcing has certainly been much larger in the past two decades. In any case, future changes in solar irradiance and greenhouse gases require careful monitoring to evaluate their future balance. In the future, if greenhouse gases continue to increase rapidly while aerosol forcing moderates, solar forcing may be relatively less important. Even in that case, however, the difference between an increasing and decreasing irradiance could be significant and affect interpretation of climate change, so it is important that solar variations be accurately monitored.